The Advances in the Carbon Source/Sink Researches of Typical Grassland Ecosystem in China

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Abstract

With the deepening research of global change, studies of carbon cycle of grassland ecosystem, one of the widely distributed vegetation type, is of great significance in estimating global carbon cycle. Grassland degradation and desertification caused by human activities(such as land reclamation and grazing etc) is becoming increasingly serious in our country, so it is urgency to study the effects of human on grassland soil carbon. Under the condition of increasing measuring precision and region density, it is superior to use remote sensing in grassland carbon storage measurement through acquisition and inversion vegetation information and related biophysics parameters, it is possible to monitor the space distribution of grassland carbon-fixed amount in large range and multi-scale timely and accurately. In this paper, the importance of carbon cycle of grassland ecosystem was discussed, and researches on carbon cycle of grassland ecosystem in China was summarized and analysed, including the three carbon pools(plants carbon pool, litterfall carbon pool and soil carbon pool), effects of natural or human activities on carbon storage and methods to estimate the carbon storage. Additionally, based on the principal of grass growth, together with analysis of various global ecosystem NPP estimation methods, we put forward a novel thought to establish an carbon estimation model and testify its accuracy with meteorological data and field observation data such as grassland biomass, NPP, net ecological productivity (NEP) etc, which is much more suitable for carbon source/sink estimation of grassland ecosystem in China. At last, the existing problems and prospects of carbon source/sink researches of main grassland in China were discussed.

Keywords: grassland ecosystem; carbon source/sink; carbon pools; grassland classification; integrated data method

1. The Introductions of Carbon Source/Sink of Grassland
Grassland ecosystem, an important part of the terrestrial vegetation, has been participating in the global carbon cycle process for thousands of years. There are 392 million square kilometers natural grassland in China, which accounts for 41.7% of the land area[1]. Generally, the carbon storage of Chinese grassland ecosystem accounts for 8% of world grassland ecosystem and about 16.7% of terrestrial ecosystem in China, and the carbon storage accounts for 15.2% of the total terrestrial ecosystem, the unit area of carbon density is higher than the world average level(Table1.)[2]. Studies have shown that our the grassland vegetation is a carbon sink, rather than carbon source. It is of great value of grassland carbon estimation in determining the ecological value and contribution of grassland vegetation, studying the terrestrial carbon cycle mechanism and global carbon balance and accurate estimation and judgment the CO2 concentration increase or decrease caused by vegetation variation.

The grassland net primary productivity(NPP) refers to the remaining part of total organisms which is generated by photosynthesis after deducting autotrophic respiration of green plants in unit of area and time. The NPP plays an important role in the global change and carbon cycle, which not only reflects the production capability of vegetation communities directly in the natural environment conditions and quality of terrestrial ecosystem, but is the main factor of ecosystem carbon source/carbon sink and the ecological processes.

At present, there are two ways in estimating the NPP:field observation and models estimation. The field observation method is simple and accurate, but it is time-consuming, arduous and destructive. What’s more, it can only be used in small area, it is difficult to carry on for large scale. Even so, the data obtained from the direct harvest method can be used in testifying accuracy of carbon estimation models, as a reference of productivity estimation.

<table>
<thead>
<tr>
<th>Grassland Type</th>
<th>Above Ground (g C/m2)</th>
<th>Under Ground (g C/m2)</th>
<th>Total C (g C/m2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>114.7 ± 13.6</td>
<td>270.6 ± 36.1</td>
<td>408.8 ± 45.7</td>
</tr>
<tr>
<td>Middle of Europe</td>
<td>446.2 ± 127.4</td>
<td>245.3 ± 39.9</td>
<td>796.1 ± 200.3</td>
</tr>
<tr>
<td>East of Europe</td>
<td>252.1 ± 53.5</td>
<td>288.6 ± 52.7</td>
<td>572.3 ± 70.4</td>
</tr>
<tr>
<td>Russia</td>
<td>180.0 ± 16.8</td>
<td>611.0 ± 143.6</td>
<td>813.5 ± 132.4</td>
</tr>
<tr>
<td>China</td>
<td>59.6 ± 14.7</td>
<td>164.1 ± 48.4</td>
<td>230.46 ± 64.9</td>
</tr>
<tr>
<td>Australia</td>
<td>376.0</td>
<td>550.8</td>
<td>973.8</td>
</tr>
<tr>
<td>Savanna</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>394.4 ± 114.9</td>
<td>334.2 ± 62.7</td>
<td>1062.7 ±203.4</td>
</tr>
<tr>
<td>Africa</td>
<td>178.4 ± 49.2</td>
<td>672.2</td>
<td>988.2</td>
</tr>
<tr>
<td>South America</td>
<td>348.1 ± 20.8</td>
<td>430.0</td>
<td>782.1</td>
</tr>
</tbody>
</table>

There are also some models in carbon storage estimation(Table 2)[3-4], which makes the multi-scale carbon monitoring possible. The NPP is affected by the soil subsystem, grass subsystem, livestock subsystem and the external environment factors. Under natural conditions, the light, heat and water is the key environmental factors of grassland NPP. The NPP estimation models derived from fields observation, statistical model to the mechanism process model. In the statistical model, the NPP is calculated through the statistical relationship among NPP, temperature, precipitation and vegetation index obtained from remote sensing data. Biological physiological processes of plants is simulated and the NPP factors are analysed in the process model, including photosynthesis, growth, respiration, evapotranspire, photosynthetic material distribution and decomposition and seasonal changes etc. With the development of "3S" technology, remote sensing technology was introduced into carbon estimation models. The remote sensing data such as surface coverage condition, vegetation canopy structure variable value(LAI), surface reflectance, surface radiation temperature and soil water regime, are applied in the remote sensing process model. Each of these methods has its characteristics and application scope, it is difficult to analyze and
compare the data obtained, and thus cause uncertainty of carbon storage evaluation of grassland ecosystem.

**Table 2. The Contrast of Grassland NPP Estimation Models**

<table>
<thead>
<tr>
<th>Models</th>
<th>Examples</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applicable Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Productivity Models</td>
<td>Miami, Thomthwatete, Chicago</td>
<td>☀️Simple. ☀️Climate parameters are easy to be obtained.</td>
<td>☀️Ecological physiological mechanism is not clear. ☀️The estimation results always differential reformation. ☀️Large estimation errors.</td>
<td>Regional potential NPP estimation.</td>
</tr>
<tr>
<td>Ecosystem Process Model</td>
<td>CENTURY TEM BIOME-BGG</td>
<td>☀️With ecological physiological base. ☀️Simulate and forecast influence on NPP caused by global change. ☀️With accurate results.</td>
<td>☀️Complicated. ☀️Need lots of parameters which is hard to obtain. ☀️Regional scale conversion is difficult.</td>
<td>Little space scale, homogeneous patches NPP estimation.</td>
</tr>
<tr>
<td>Light Energy Use Efficiency</td>
<td>CASA, GLOPEM, SDBM</td>
<td>☀️Can be promoted to the whole world. ☀️The parameters can be obtained from remote sensing data. ☀️The season and inter-annual dynamic can be obtained.</td>
<td>☀️Ecological physiological mechanism is not clear ☀️Cannot simulate and forecast the NPP. ☀️There are lots of uncertainty in the light transformation and conversion.</td>
<td>Regional and global NPP estimation.</td>
</tr>
</tbody>
</table>

at present, the CASA and CENTURY model are widely used in grassland NPP estimation in the world.

2. Research Contents and Tasks on Carbon Source/Sink of Main Grassland Ecosystem in China

The distribution of grassland ecosystem in our country is mainly affected by heat and moisture, and mainly distributed in the arid and semiarid region of the annual precipitation above 400 mm, south and eastern humid, semi-humid regions and east and south coastal zones, etc. There are three main areas of natural grassland in China: north temperate grassland, the qinghai-tibet plateau alpine grassland and Southern grassplot(Fig 1.).

1. Northern Temperate Grassland

The northern grassland is located in northwest of 400 mm rain line, from Greater, Lesser Higgnan Mountains to the west, southwest part until boundary line of west of Sinkiang, which accounts for 41% of the total grassland area, one of the main pasture husbandry areas in China. Northeast prairie grassland and The northwest desert grassland are typical type in this area.
Northeast prairie grassland is the main part of natural grassland in China, it is of great significance in improving the environment and adjusting global carbon balance, slowing concentration of CO₂ and other greenhouse gases, maintaining global climate stability. It is also an important base of animal husbandry in China with high economic value. The northwest desert grassland in China, located in the most drought heart of the continent of Asia, developed under the condition of the temperate zone, warm temperate zone and drought, super drought of heat and moisture. From the middle of 1980s, many scholars have studied the quantity relationship between biomass of guineagrass, Stipa grandis community and hydrothermal condition of the Xilin river basin, Inner Mongolia. Wenhong Ma et al. did a large field observation of temperate grassland of Inner Mongolia, and estimated carbon storage of grassland in this area.

2. The qinghai-tibet plateau alpine grassland

The qinghai-tibet plateau grassland sectors are connecting, accounts for 38% of the total grassland area. The hydrothermal condition is poor, and productivity is low in this area, and 12% of grassland is hard to be utilized currently. The natural condition in this area is quite rough and fragile because of the alpine climate. There are lots of ecological environment problems, such as grassland degradation, grassland ecosystem function weaken and desertification etc. caused by natural disturbance and human activities. The soil is rich of organic, soil carbon density is higher than other areas obviously. In recent years, lots of researches indicates that the soil carbon storage of qinghai-tibet plateau is higher, but it has been deduced due to the widely disturbance to the alpine meadows ecosystem caused by natural and artificial factors since 1980s. Based on the remote sensing data, meteorological data and other related data for many years, Gao Qingzhu et al. analyzed the grassland net primary productivity (NPP) and its spatiotemporal distribution of Northern qinghai-tibet by CASA (Carnegie—Ames-Stanford Approach) model.

3. Southern grassland

There are lots of grassplot in south parts of China, accounts for 12% of the total grassland area, most of them are fromed by the secondary forest vegetation after repeatedly destruction, and distributed in most hills and mountains altitude below 1000 meters. Because grassplot, forest and farmland are mosaic, grassplot resource has great dispersibility. The grassplot can be divided into tropical grassplot and subtropical grassplot according to the climate of southern. Tropical grassplot distributed in Guangdong, Hainan, Guangxi and Yunnan. Most herbage here are drought-enduring with little leaves. The climate here is humid with high temperature and more rain, long summer and no winter. Subtropical grassplot are widely distributed in Yunnan, Guizhou and other provinces. These provinces has a mild climate, abundant precipitation, long period of frost-free. Most regions are evergreen, abundant with water and grass. Most herbage here are tall gramineae grass with more Leguminous grass and poisonal grass.
4. Three Carbon Pools of Grassland Ecosystem

The carbon cycle of grassland ecosystem is one of the basic mechanisms to sustain the terrestrial ecosystem. In grassland ecosystem, the grassland plants absorb CO$_2$ through photosynthesis, synthesize organics, plants fall onto the soil surface after dead to form the litterfall layer and transfuse into the soil pool, part of which was settled in the soil through humification. These decomposition products would be reused by plants through soil animal and microbe mineralization. This is the internal carbon biological cycles of ecological system. What’s more, parts of organic carbon fixed by photosynthesis release to the atmosphere in the form of CO$_2$ through their breathing, autotrophic respiration, grassland animals respiration, heterotrophic respiration of litterfall layer and soil respiration metabolism, which compose the biogeochemical cycle among grassland plants, soil and atmosphere. In the grassland ecosystem, the plants, litterfall and soil compose the three carbon pools, it is the core of the entire grassland carbon source/sink research that the carbon storage of each pool, carbon flux among pools and their changes (Fig 2).

Fig 2. The three carbon pools in grassland ecosystem and carbon flow process in it.

A. Plant carbon pool. Atmospheric CO$_2$ will be transformed into organic carbon by green plants through photosynthesis, which is the main source of grassland ecosystem carbon, the grassland net primary productivity (NPP) reflects differences of different grass community types photosynthetic carbon-fixed ability in a certain extent. NPP and carbon inputs of tropical grassland is higher than that of temperate grasslands. In the temperate area, carbon fixed ability of semi-natural grassland communities of Europe and Russia is a litterfall higher than north American temperate grassland communities, but carbon inputs is the lowest of our temperate typical steppe. This trend is substantially consistent with moisture conditions and the rainfall variation. Grazing will change the structure of grassland ecosystem communities, and reasonable determination of grazing intensity is not only beneficial to grassland stockbreeding development, but also important enhancement to the entire plant carbon-fixed ability.

B. Litterfall carbon pool. Besides carbon accumulation inside, carbon that gradually transfused into soil carbon pool in the form of litterfall is also great. Grassland litterfall carbon pool is the important intermediate link of grassland plant carbon pool and soil carbon pool. Seasonal dynamic change of litterfall reflected the dynamic change of carbon exchange between grassland plant carbon pool and soil carbon pool to a certain extent, the formation and decomposition of litterfall usually accompanies with reduction of plant carbon pool and increase of soil carbon pool. At least 20% ~ 50% of the above ground net primary productivity of grassland communities transfused into soil carbon pool in the form of litterfall and livestock wastes. According to preliminary estimates, carbon storage of litterfall carbon pool point is 30 ~ 400g/m$^2$, slightly higher than aboveground biomass on average.

C. Soil carbon pool. Researches on grassland soil carbon pool and its change and regulation mechanism are the core of grassland carbon cycle research. As to the grassland ecosystem, plant roots and soil microbial respiration rate and seasonal change are mainly controlled by soil temperature and water condition, also different due to community types and geographic location. So far, researches on soil respiration focuses on the temperate grasslands in north America, India and some tropical grassland
communities in Australia. Moreover, these researches are mainly about short-term flux of soil respiration, seasonal dynamic, climate, reclamation, but less about grazing. In the grassland ecosystem, soil organic carbon mainly comes from plant residual roots, decomposition of litterfall layer also contributed to the soil organic carbon storage. Grassland soil carbon mainly exists in the form of organic matter, and mainly focus on 0~20 cm of surface soil. Even the different profile level of the same soil types, differences of soil organic carbon content are also obvious, soil organic carbon content of surface 0~1 cm is 4~10 times as that of deep soil 80~100 cm. Actually, the main process of grassland ecosystem carbon cycle is completed in soil. Generally, organic carbon of grass soil changes greatly, estimated at 90~15000 gC/m². Soil organic carbon of temperate grassland is obviously higher than that of tropical grassland, meanwhile, soil carbon of tropical grassland surface takes higher percentage of total soil carbon, with temperate grassland is relatively low.

5. Factors Affect Grassland Carbon Cycle

It is reported that global change will affect the grassland ecosystem firstly in all sorts of terrestrial ecosystems, and effects of land use changes on grassland carbon cycle is much more significant than climate and CO₂ concentration changes. Due to the effects of human activities, land use of grassland have changed substantially, reclamation, grazing fencing and burning are all factors that affect carbon storage of grassland, so it is of great significance to understand and master the transformation of grassland ecosystem types caused by human activities correctly.

Reclamation and grazing is the main activity that human make use of grassland and affects soil carbon storage. As long as the influence intensity is concerned, grassland reclamation is the main intense human activity factor that affects grassland soil carbon. Reclamation make the soil organic expose to the air, change the soil temperature and humidity, and thus enhance the soil respiration, accelerate the soil organic decomposition. The soil carbon will lose 20%-30% if grassland reclaimed for farmland. The soil organic carbon has reduced 12.4% after 40-years’ over-grazing on leymus chinensis steppe of Xilinhaote in China. As to the influence scale, over-grazing is the most powerful factor that human affects grassland, 35% grassland degradation is caused by over-grazing worldwide, much more than reclamation. Reclamation has dramatic impacts on the soil carbon storage. According to Ojima, etc (1993) if the grazing level increased to 30%~50%, most carbon of grassland in warm areas will in next 50 years, but moderate grazing and maintaining the sustainable management will reduce carbon emissions, increase soil carbon source/sink.

At present there have been many researches on relevant grassland management measures and effects of grassland utilization on carbon accumulation of grassland ecosystem. For example, fertilizer will increase carbon storage of grassland ecosystem, desertification is harmful to grassland soil carbon storage and grassland NPP, grassland fire can also lead to the loss of carbon storage, especially in tropical savannas areas.

3. Prospects

From the above review, we can see that carbon cycle research of our grassland ecosystem is still in the early stage basically, the existing research targeted at carbon cycle are weak, so the following aspects in the future carbon cycle studies should be further strengthened in our country:

To study carbon cycle and balance through the overall and systematic view. At present, researches on plants, litterfall and soil are all confined to their own time changing trends, space distribution and environment factors, researches are independent relatively. So we need take more efforts on process and strength of grassland carbon cycle through different time scales and space area, strengthening the
contrast positioning observation of seasonal changes and regional differentiation of grassland carbon source/sink, exploring possible changes of carbon cycle process affected by human activities, quantitative analysis of interaction mechanism of climate change, land use change, human activity intensity.

The existing carbon storage data are lack of comparability, and studies of factors that influence ecological system carbon accumulation is insufficiency. So we should establish a unified observation method and standard monitoring network of grassland ecosystem productivity and grassland resources, perfect the foundation database construction of grassland resources, and strengthen researches on the main control factors of carbon accumulation of grassland ecosystem and multiscale grassland ecosystem carbon storage mechanism and process driven by climate change and human activities, pay more attention to the grassland ecosystem underground carbon pool.

The remote sensing data, such as LAI, NDVI, MODIS can reflect the special spectral physiology characteristics of ground green plants and annual and interannual precipitation of years, monitor grassland conditions changes and determine areas of grassland primary productivity changing. Based on this, we are developing an integrated NPP estimation model, which takes the photosynthesis, growth status, respiration, evapotranspire and photosynthetic material distribution into consider. Photosynthetic available radiation absorption (PARA) of vegetation components is acquired by remote sensing spectral decomposition and solar radiation reached the surface vegetation and photosynthetic available radiation absorption efficiency is obtained by remote sensing data or climate data in this novel model, and then the carbon is calculated through the energy conversion coefficient. The integrated model strengthens the application of remote sensing technology in grassland ecosystem carbon source/sink researches and realize rapid diagnosis and evaluation of the time and space distribution pattern of source/sink of grassland ecosystem.

4. Acknowledgement

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