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Management Strategies and Their Evaluation for Carbon Sequestration in Cropland

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Abstract In order to deal with the global change and to reduce emission of greenhouse gas, a number of countries have strengthened studies on carbon sequestration in cropland. Carbon sequestration in cropland is not only an important component for the global carbon stock, but also is the most active part to sequestrate the carbon in soil from atmosphere. In this sense, it is of necessity and significance to strengthen the study on management of carbon sequestration in cropland. Based on the main factors affecting carbon cycle in agro-ecosystems, this paper summarizes the relevant management measures to strengthen the capacity of reducing emission of carbon and increasing the carbon sequestration in cropland, and evaluates the effects of these measures after being implemented at a regional extent
Key words Carbon sequestration; Carbon sequestration in cropland; Soil organic carbon; Management of carbon sequestration; Reducing carbon emission; Increasing carbon sequestration

With the more and more in-depth researches on global environment change, the management strategies for carbon sequestration in cropland have been widely given attention. Current researches show that the missing of carbon most probably exists in the terrestrial ecosystem[1-2]. Although there are many literatures focus on the carbon sequestration of terrestrial ecosystem in China[3-4], researches on carbon cycle in cropland are relatively few. The management measures for carbon sequestration in cropland affect the dynamic changes of soil organic carbon (SOC) to a greater extent. The excessive reclamation and improper management will greatly reduce the SOC amount of cropland so as to cause the massive emission of CO_2.

Optimization of agricultural management measures can not only increase the soil carbon sequestration, improve the soil quality and enhance the agricultural productivity, but also reduce the soil and water loss, protect the biotope landscape, etc. It should be noticed that the potential of carbon sequestration in the top soil is not only influenced by the vegetation condition, environmental temperature, the compositions of soil mineral, weathered layer depth, soil drainage, the availability of water and air, etc., but also is controlled by the chemical composition of soil organic matters and their resistance to the microbial degradation[5]. When potential of carbon sequestration in top soil is calculated, the emission of CO_2 should be considered due to consuming fossil energy in the process of fertilizer production, water diversion irrigation, agricultural machinery work, etc. Therefore, more and more research efforts should be made to explore the sequestration mechanism and potential of SOC content in the top soil, and to formulate the optimal agricultural management measures under local conditions so as to improve the potential of carbon sequestration in cropland and mitigate the impacts from climate change in China[6].

Increasing the carbon storage of agro-ecosystem is generally taken measures from two aspects: One is reducing the carbon loss, whose main measures contain improving the energy utilization ratio, reducing the water and soil loss and improving the water-fertilizer utilization ratio; and the other is increasing SOC content, whose main measures contain adjusting the farming system, applying the organic fertilizers, using the deep-root crops and increasing the content of micro-aggregates in soil[7]. Aiming at above aspects, some scholars put forward many management strategies for carbon sequestration in cropland (Table 1). Several management measures for carbon sequestration in cropland to be extended easily were described in this paper.

Table 1 Management strategies to increase SOC content in cropland

Management strategies	Feasibility	Relative increasing amount of carbon
Minimum tillage or no-tillage	High	Middle
Ground cover	High	Low
Reducing summer fallow	Middle	Middle
Rotation	Middle	Middle
Improving varieties	High	Middle
Organic fertilization	Middle	Middle
Irrigation	Low	High

Data are adapted from Jin et al (2000) in which a little modification was made.

Management of Land Use Transformation

Land use transformation will cause the changes of vegetations and soil carbon storage, which makes the management of land use transformation become one of important measures to increase soil carbon sequestration. In order to coordinate the relationship between increasing the potential for carbon sequestration in cropland and leaving enough land area to develop agriculture at regional extent, it needs to reasonably plan the distribution of different land use patterns and scientifically and rigorously control the land use transformation

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between cultivated land and other types of land use.

Among the land use types including cropland, grassland and forest, the carbon sequestration function from forest is the strongest, especially the natural forest ecosystem has stronger protective component of carbon so as to have strong carbon sequestration stability (Table 2); the water and soil loss is the main process to cause the loss of SOC, and the degraded land has lower SOC storage, then the water and soil loss can be controlled through forestation or planting perennial plants so as to recover the degraded land, thus improving the SOC content in the top soil[8]. Therefore, through the changes of soil use types like transforming the low-yield and degraded croplands into grassland or forest, intensive management of cropland, carrying out the management modes of agro-forestry and forest-grass compound, transforming the single land use type into multiple land use types, etc., the storage and stability of SOC can be improved, thus increasing SOC and the carbon sequestration in cropland.

Table 2 Storages of biomass and debris carbon, SOC and its fractions and carbon pool under various land use types t/hm^2

Land use types	Natural secondary shrub	Natural secondary poplar forest	Cropland	Grassland	13-year secondary larch forest	25-year secondary larch forest
Biomass carbon	21.44	33.02	1.32	2.71	18.45	53.03
Fine debris carbon	7.89	7.41	0.73	1.99	5.54	7.71
Coarse debris carbon	1.03	1.09	0.10	0.41	0.92	0.30
Total of debris carbon	8.92	8.51	0.83	2.40	6.46	8.01
Soil organic carbon	156.68	158.50	96.75	134.99	106.62	143.93
Active organic carbon	15.39	16.13	8.44	12.87	10.97	14.82
Light fraction organic carbon	39.08	46.90	30.58	46.82	44.04	50.69
Particulate organic carbon	28.88	32.04	25.78	29.84	32.30	44.55
Non-protective organic carbon	35.56	35.43	28.42	37.68	33.76	43.94
Protective organic carbon	107.31	110.33	60.12	83.79	57.48	81.49
Non-stable organic carbon	99.10	83.87	60.67	67.12	60.08	86.10
Stable organic carbon	55.35	70.72	35.86	65.60	45.34	59.13
Total of system carbon pool storage	187.03	200.02	98.89	140.10	131.53	204.97

Data are adapted from Campbell et al (1991) in which a little modification was made.

Adjustment of Cropping System

Cropping system has great influence on the carbon storage in cropland, for example, tillage can result in a carbon loss of 8×10^{11} kg every year globally[9]. The main measures to adjust the cropping system contain promoting no-tillage practices, expanding the rotation practices and improving multiple-cropping index.

Promotion of no-tillage practice

No-tillage practice is a tillage method with the minimum soil disturbance, which can improve the SOC in cropland effectively. No-tillage practice not only can improve the quantity of soil aggregates and stability so as to reduce the decomposition of organic matters within aggregates[10-11], but also can inhibit the excessive aeration of soil and reduce the oxidative degradation of organic carbon so as to prevent the soil erosion[12-13]. In addition, the average sequestration time for organic carbon in no-tillage soil will double than the time spent in conventional tillage soil[14]. So the content of organic carbon in no-tillage soil is generally higher than that in conventional tillage soil. According to the researches by West et al[15], the storage capacity of organic carbon in soil has an average annual increase of (57 ± 14) g/m^2 after taking no-tillage practices compared with insisting on the conventional tillage.

However, there are some disputes about the enhancement effects for carbon sequestration by taking no-tillage practices. Researches showed that the content of organic carbon in the top soil was increased significantly[10], but went against roots to grow deeply[11]. Campbell et al[16] held that no-tillage could not always improve the soil organic matter content under the poor soil. The researches by Doran et al[18] suggested that no-tillage could also result in the carbon loss of surface soil under the wheat/fallow pattern, furthermore only by improving the multiple cropping index, decreasing the fallow frequency and increasing the organic carbon input to the top soil, could the decrease rate of the content of soil organic matters be slowed down, otherwise, content of soil organic matter might increase in the top soil.

Expanding rotation practice

Rotation can improve the efficiency of carbon sequestration in soil, and is an important practice to keep and improve the stability of cropland ecosystem. The influx of soil organic matters can be improved by adding legume crops or leguminous grass during the rotation process, mainly because the legume plants can play the function of biological nitrogen fixation, the ratio of carbon to nitrogen (C/N) in roots and residues of crops is low and the decomposition is speeded up, and then can improve the content of soil organic matters[19]. Besides, other research showed planting crops with high residue ratio can reduce the surface evaporation of water in soil and strengthen the ability of holding and keeping water in soil so as to promote the sequestration of SOC[20]. A long-term research, lasting for thirty-five years, conducted by Gregorich et al[21] showed that cropping system had a larger effect on soil carbon than fertilization, furthermore the content of soil carbon under the rotation of maize and legume crops was 20 mg C/(hm^2 · a) higher than that under the maize monoculture. Huggins et al[17] also found that adding the perennial herb or legume plants to rotation system was beneficial to the storage of SOC. Guo et al[22] studied the response of SOC in semi-arid area to the rotation system in Changwu County, Shaanxi Province, and concluded that the rotation system affected the input of soil carbon significantly, furthermore there was significant linear correlation between the carbon sequestrated in soil and the cumulative input organic carbon in soil proved by an eighteen-year experiment. Therefore, the adjustment of crop-grass rotation is an effective way to improve the soil quality and realize the potential of carbon storage of soil.

However, Campbell et al[16] found that when water was not sufficient and the forage biomass was low, the influx of soil organic matters was not obvious after adding forage in rotation; only when the climate condition was of benefit to vegetative growth, the influx of soil organic matters could be increased. Through long-term researches on the effects of agricultural management measures on the quantity and distribution of SOC content, Potter et al[23] found that the crop rotation had great effects on the content of SOC, however, the SOC accumulated by one crop in rotation system could be lost due to the lower biomass of another crop in this system.

Improving multiple-cropping index

Improving multiple-cropping index and decreasing fallow frequency can improve crop yield and also increase the organic matter input from crop residues and roots in top soil so as to increase the SOC content. When the organic matter input is increased, the degradation rate of microorganism is also improved, but the content of soil organic matters is still improved to a certain degree generally due to that the input SOC is more than the lost SOC during the humus decomposition process[24].

Most researches suggested that the soil carbon influx was directly related to the fallow frequency. Researches showed that net carbon loss of wheat fallow planting pattern was 20 to 25 g/m^2 higher than that of wheat continuous cropping in conditions of the same carbon input[25], which means that decreasing the fallow frequency can relatively slow down the decomposition rate of soil organic matters (SOM) so as to make more carbon sequestrated in soil. He et al[26] also found that rape multiple cropping can prolong the covering time of surface green, reduce wind erosion and water erosion, decrease the water evaporation of soil effectively, increase SOM, and improve the soil fertility after the decay of underground residues.

More Intensive Field Management

Reasonable application of fertilizers

Application of fertilizers in field can affect the supply of soil carbon by influencing the biomass of standing vegetation, the soil microbial activity and the soil respiration rate, so change of the intensity of fertilizer use can cause the carbon sequestration in top soil of crop land to change[27]. The long-term experiment suggested that application of organic fertilizers could improve the content of SOC significantly[28-29]. However, there are no coincident conclusions about the effects of applying chemical fertilizers on the content of soil carbon. Massive long-term experiments indicated that the long-term application of fertilizers in the crop field was beneficial to increasing the content of SOC, especially applying enough fertilizers into the soil with lower content of organic matters had a significant and positive effect on improving the content of SOC, but there was a certain limit in the effect of chemical fertilizers on SOC[27]. There are also some opposite conclusions. For example, Yu[29] found that application of fertilizers could result in the decrease of SOC content and reduce the interception of soil carbon; the effects of various kinds of fertilizer combinations would result in various results, and the combination of nitrogen and phosphorus fertilizers had more significant effects on reducing SOC content than the single fertilization from using nitrogen fertilizer and the combined fertilization of nitrogen, phosphorous and potassium fertilizers.

There are some differences in the effects of different fertilization modes on SOC composition. Ma et al[30] held that applying organic fertilizers alone or together with inorganic mineral fertilizers could input the organic carbon and improve the soil physical properties so as to increase the total amount of SOC the content of active organic carbon. Researches by Xu et al[31] indicated that long-term applying the inorganic mineral fertilizers only, especially inorganic nitrogenous fertilizer, could promote the root growth, increase the residues of plant roots, etc.; however, due to the decrease of w(C)/w(N) in top soil and the improvement of soil microbial activity so as to accelerate the decomposition and mineralization of the original carbon and fresh organic carbon in top soil, the total amount of SOC was decreased, the decrease of light fraction organic carbon greatly exceeded that of heavy fraction organic carbon, resulting in the content increase of SOC which is difficult to be oxidized and the promoted aging process of SOC.

Researches on the fertilization modes under various kinds of soil types, climate conditions and land use patterns showed that applying organic fertilizers alone or together with chemical fertilizers could improve the content of SOC significantly[28, 32], which should be the priority selection in the enhancement measures for carbon sequestration in the top soil of cropland.

Improving water conditions in top soil

The water condition in top soil of cropland is one of the decisive factors for cropland soil to discharge or absorb the atmospheric greenhouse gas, so improving the water conditions of soil is a main way to change the emission and composition of soil greenhouse gas. The waterlogged soil discharges CH_4 to atmosphere, while the cropland soil with good drainage oxidizes CH_4 in air. Besides, the water condition in cropland is also an important factor to affect the decomposition rate of SOM and the emission of CO_2.

Artificially changing water condition of cropland can adjust the total, compositional and potential emission effect of greenhouse gas discharged by the top soil in crop land. Normal soil has the strongest oxidative ability when its water content accounts for 15% to 40% of field moisture capacity, but the paddy soil mainly oxidizes the CH_4 generated in soil, so the emission of CH_4 is closely related to the water content in soil. The composition and total amount of greenhouse gases (like CO_2, CH_4, etc.) discharged by paddy soil are affected by the water types of soil, furthermore there are significant differences in the emission rates of various greenhouse gases as the incubation time changing. Researches showed that the emission rate of CO_2 increased in the long-term flooding soil but decreased in the good gas soil gradually as the time prolonging. The intermittent irrigation can be carried out to reduce the emission of greenhouse gas in cropland, which is an effective measure to reduce the emission of CH_4 in paddy field. Besides, improving the groundwater level during the proper growth period is also benefit to the emission reduction of CH_4 in paddy field. An experiment conducted in Japan in 1991 proved that if there was a 10-day emission of water at the tillering stage and heading stage respectively, the total emission of CH_4 in growing season would decrease by 1/2[33].

Perfection of the crop residue utilization

The dynamic changes in SOM content are directly related to the quality of organic matters input to soil, and the changes of SOM are affected by crop residue input in a large degree. The decrease of organic carbon input in cropland after crop harvest is an important reason for the decrease of carbon storage in cropland. In traditional agricultural management system, tillage and clearing crop residues will result in the loss of SOM and the decrease of the proportion of micro-aggregates in soil. Researches by Huggins[17] suggested that the content of SOC decreased rapidly with the carbon input decreasing; furthermore the short-term increase of SOC mainly depended on more carbon input and the fixing efficiency of unstable carbon sequestration, and returning crop residues to field can also promote the carbon sequestration in top soil.

Li[34] found that the use patterns of top soil and the intensity of field management were main reasons for various dynamics of agricultural soil carbon sequestration between China and America, among which, the most striking difference was the treatment methods of crop aboveground residues (and straw) between China and America, for example, the returning rate of straws was up to 90% or so in America but less than 20% in China, so improving the returning rate of straws is one of effective means to enhance the carbon sequestration in cropland in China. Zhu et al[35] conducted a case study on the content of SOC in Rugao County of Jiangsu Province, and concluded that returning straw to field was the main reason to drive the changes of SOM content in recent 20 years judged from the general trend of change. From the early 1980s to 1997, returning maize straws to field was popularized and applied in large-area production in Rugao, and the returning area was increased year by year, especially in the central and western regions such as Motou system and Guoyuan system distribution area, where the most straws of summer dry crops such as maize were returned to field so as to increase the content of SOM rapidly during the stage, furthermore there were significant differences among them.

The increase of residues and SOM sequestration can improve the water use efficiency and nutrient recycling ability of plants so as to reduce the nutrient loss and enhance the carbon influx. But there is a balance between carbon input and SOC, and when the balance is reached, the potential of improving SOC content by increasing carbon input will decrease. Adding crop residues into soil can improve properties of the soil, furthermore there are different effects of different tillage measures with crop residue management on the components of SOC. As for the soil with low clay content or microbial decomposition done easily, the SOC with unstable storage maybe mainly depend on increasing crop residues returning to field and decreasing the tillage. The addition of residues can improve the soil microenvironment and promote the storage of soil carbon, but there are different effects of crop residue management on SOC under the different tillage measures[6].

Indispensability of the Technological Progress

There are many other ways to enhance carbon sequestration and reduce emission of carbon from cropland ecosystem, such as improving crop varieties and cultivating varieties resistant to the extreme climate event (e.g. high temperature, drought, etc.) as well as diseases and pests, so as to increase crop yields continuously in the new ecological environment and the absorption storage of carbon. It is estimated that reduction of CH_4 emission can reach 20% to 30% by selecting adaptive rice cultivars, meanwhile adopting methane inhibitors is also an effective way to reduce the emission of methane. There are two methane inhibitors, AM1 and AM2 developed by Institute of Agricultural Meteorology, Chinese Academy of Agricultural Sciences, whose main raw material is humic acid capable of transforming organic matters into humus so as to increase rice yield and reduce the substrate from which methane will be produced.

In addition, using new energy-saving parts of agricultural machines to refit agricultural machines (like tractors, etc.) can also reduce the emission of carbon in cropland and increase the potential of carbon sequestration in cropland.

Conclusion

At present, the measures to increase the carbon sequestration in cropland mainly include reducing the carbon loss and increasing SOC. The main effective measures to reduce the carbon emission consist of improving the utilization ratio of energy, reducing the loss of water and soil, and improving the utilization ratio of water and fertilizers while the measures to increase SOC in cropland mainly contain adjusting the tillage system, applying the organic fertilizers, growing the deep-root crops and increasing the content of micro-aggregates in the top soil of cropland. By analyzing the effectiveness of various measures and practices for carbon sequestration in cropland, this paper concludes that the effective measures to increase the carbon sequestration in the top soil of cropland will mainly contain promoting the management of land use transformation, adjusting tillage system, applying reasonable fertilization, improving the water conditions of soil, perfecting the crop residue management, etc. It is noteworthy that due to the differences of regional natural conditions and social-economic conditions, the concrete implementation should be adaptation to local conditions and under the guidance of local economic development planning so as to fully make full use of the advantages of management measures.

Climate condition is an important factor to affect the SOC dynamics in the top soil of cropland. Under the context of global changes, coupling the management strategy of carbon sequestration with the effects of climate change and clarifying the feedback mechanism of changes of SOC content in the top soil of cropland on the comprehensive effect of natural factors (like climate, soil, etc.) and management factors are of important significance to predict the change trend of carbon sequestration in cropland in future.

The management strategy of carbon sequestration will affect agricultural production, so clarifying the influence mechanism is very important to guide the optimal management of cropland in China. However, the researches about the effects of management strategies of carbon sequestration in the top soil of cropland have made certain progress at home and abroad, but few scholars carry out studies from the view of the sustainable development of agricultural production and the conservation of ecological environment. Therefore, it is necessary to explore the comprehensive effects of different combinations of management strategies of carbon sequestration on enhancing the functions of the carbon sequestration in cropland and ensuring the development of agricultural production under the conditions of climate change.

It should be noted that the expected effects after taking the management strategies of carbon sequestration have been mostly proved by the field experiment. Therefore, on one hand, the effectiveness of those strategies needs to be diagnosed at more macro scale; on the other hand, researches on the mechanism resulting in the effects of carbon sequestration from management strategies are relatively weak under various kinds of soil-climate-crop belts. Last but not the least, quite few models used for analyzing the effects of management strategies on carbon sequestration are not capable of case study in China, while the relevant models developed out of China still need to be localized, which means that modules and parameters embedded in those models need to be tailored to the conditions in China.

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农田碳汇管理策略及其效果评价

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摘要 目前增加农田生态系统的碳储量的措施主要有:减少碳损失,包括提高能源利用率,减少水土流失和提高水肥利用率;增加土壤有机碳,包括调整耕作制度,使用有机肥料,应用深根作物和增加土壤中微团聚体的含量。在分析各种策略与措施的基础上,笔者认为以下几种农田碳汇管理措施有效且较容易推广。①实施土地用途转换管理:把低产及土壤退化严重的农田变成草地或森林;集约管理农田,实行农林复合、林草复合经营方式;在区域或地区尺度变单一土地利用方式为承担不同人类需要的多种土地利用方式等。②调整耕作制度:免耕不仅使土壤团聚体的数量和稳定性增加,从而减少了团聚体内部有机质的分解作用;还能有效地抑制土壤的过度通气,减少有机碳的氧化降解,防止土壤侵蚀;此外,免耕土壤有机碳的平均滞留时间比常规耕作土壤增加了约 1倍。轮作能提高土壤固碳效率,在轮作中加入豆科作物或豆科牧草更可增加土壤有机质汇集,是实现土壤蓄存碳潜力的重要途径。提高复种指数,降低休耕频率可以提高作物产量并增加土壤作物残茬和根的有机质输入,从而增加土壤中有机碳的含量。③改善经营与管理:有机肥或有机肥和化肥配合施用,能显著提高土壤有机碳含量,应当优先选择;人为改变土壤的水分条件可以调节土壤排放温室气体的总量、组成及其产生的潜在温室效应;残茬和土壤有机质库的增加,可以改善植物的水分利用效率和营养再循环能力,减少养分流失,加强碳汇集。④依托技术进步:如改良作物品种,有计划地抓紧培育具有对高温、干旱等极端气候及病虫害有抗性的品种,确保在新的生态环境中产量不断提高,扩大碳的吸收存储。此外,采用新型节能的农机部件对拖拉机等农业动力机械进行改装,也可减少农田碳排放,增加农田碳汇的潜力。

关键词 碳汇;农田碳汇;土壤有机碳;碳汇管理;减排;增汇

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贵州食用蕨类植物资源分布及开发利用

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摘要 实地调研结合文献资料分析,初步明确了贵州可食用蕨类植物共计 23科、30属、64种(含 5变种),占贵州省蕨类植物科、属、种数的 42.59%、19.74%和 8.13%。对 64种贵州食用蕨类植物区系组成特点及资源分布进行了具体阐述,其中在开发利用中应重点保护的贵州珍稀及濒危物种有问荆、瓶尔小草、铁芒萁、金毛狗、桫椤、水蕨、镰羽凤了蕨、阔带凤了蕨、禾秆蹄盖蕨、短羽蹄盖蕨、中华荚果蕨 11个品种。贵州可食用蕨类植物资源丰富,具有较高的开发利用价值,从长远发展的角度看主要应做好以下几方面工作:深化食用蕨类植物的资源研究工作;开展食品深加工技术研究;开展保健功效物质基础及食品毒理学研究;制定相应的法规及资源开发和可持续利用的长远规划等。

关键词 贵州;食用蕨类;种类;资源分布

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简 讯 2009年 10月 24～25日,本刊编委吴常信院士来安徽省农业科学院指导工作。编辑部向吴院士汇报了刊物近两年尤其是 2009年重组编委会以后的发展情况。吴常信院士充分肯定了刊物取得的成绩,并对刊物今后的发展提出了建设性的意见。

吴常信,动物遗传育种学家,畜牧学家,浙江嵊县人。1957年北京农业大学畜牧系毕业。中国农业大学动物科学技术学院院长、教授。长期从事动物遗传理论与育种实践研究。在选种理论中,首次提出了"数量性状隐性有利基因"的假设,并通过实验得到证实。在参数估测中,首次提出多胎动物"混合家系"的概念,推导了计算混合家系亲缘相关的理论与近似公式,这在改进遗传参数估测方法上是一种创新,提高了选种的准确性。1995年当选为中国科学院院士。