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REVIEW

AGRICULTURAL GREEN DEVELOPMENT TO ACHIEVE FOOD SECURITY AND CARBON REDUCTION IN THE CONTEXT OF CHINA'S DUAL CARBON GOALS

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KEYWORDS

agriculture, carbon neutrality, carbon peak, food security, carbon mitigation strategies

HIGHLIGHTS

- To achieve food security, Chinese agriculture–food system could not achieve C neutrality.
- China's dual carbon goals has put forward more strict requirements for the green development of agriculture.
- The realization of C mitigation potential lies in the extensive application of existing technologies and technological innovation.

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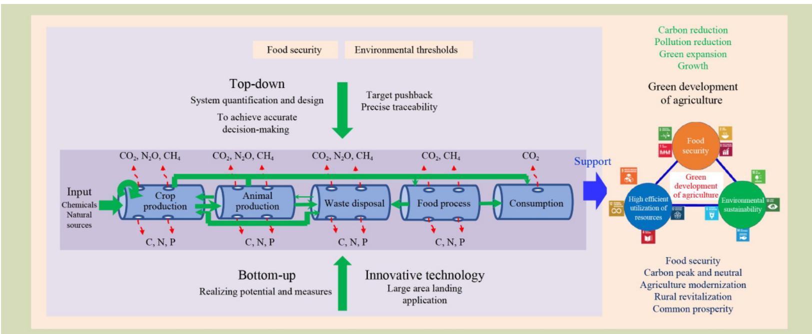
GRAPHICAL ABSTRACT



ABSTRACT

The agricultural sector, a major source of greenhouse gas emissions, and emissions from agriculture must be reduced substantially to achieve carbon (C) neutrality. Based on a literature analysis and other research results, this study investigated the effects and prospects of C reduction in agricultural systems under different scenarios (i.e., methods and approaches) in the context of China's dual C goals, as those working in the agricultural sector have yet to reach a consensus on how to move forward. Different views, standards, and countermeasures were analyzed to provide a reference for agricultural action supporting China's C neutrality goal.

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1 BACKGROUND

Climate change is a worldwide challenge facing humanity, seriously threatening global ecosystems[1]. China is the largest carbon (C) emitter, accounting for 25% of annual global emissions[2]. To improve global environmental governance, an active and ongoing response to climate change is needed to create a sustainable future for society and the environment. China has promised to reach peak CO_2 emissions before 2030 and achieve C neutrality before 2060, referred to as the 'dual C goals'[3]. China has set a period of only 30 years between C peak use and C neutrality, much less than developed countries (e.g., Europe and North America), which generally project a period of 45–70 years from C peak use to C neutrality[4].

Considering the large C emission in China, it represents a huge challenge to achieve C neutrality in such a short period.

Much of the recent discussion about C neutrality has focused on energy and industrial sectors, especially how to replace coal and gas with renewable energy. However, the agricultural sector has not received necessary attention[5–7]. The agricultural sector is a major contributor to both C emissions and C sequestration, which has significant implications for meeting China's dual C goals. As a major source of C emissions, the agriculture–food system contributes 16.7% to China's total emissions (estimated at 1670 $Tg \cdot yr^{-1}$ CO_2 equivalent)[8]. Some studies have evaluated the soil C sequestration potential at around 22.9–27.8 $Tg \cdot yr^{-1}$ C in China[10–13]. Many studies have shown that optimizing agricultural technologies can considerably reduce C emissions and increase C sequestration. For example, the integrated soil–plant management system can reduce greenhouse gas (GHG) emissions in Chinese cereal production by 11%–23%[14]. Optimizing irrigation (i.e., quantity and timing) can reduce GHG emissions by 20%–25% for Chinese maize production[15]. Improving manure management practices, such as optimizing grazing-land management and increasing the use of manure on cropland, can substantially mitigate indirect GHG emissions[16,17]. Straw retention benefits soil C sequestration, increasing annual C accumulation by around 34 $Tg \cdot yr^{-1}$[18]. However, it is evident that the agricultural sector has always been regarded as a net emission sector[19]. Therefore, the challenge is to empower the agricultural sector to help meet China's dual C goals, and additionally, identify the specific problems to be solved and their order of priority.

2 PROBLEM AND CHALLENGE

Food security has always been a primary concern in China because China feeds 22% of the world's population with serious water limitations[20,21]. In China, ensuring food security is the premise for the agricultural sector to pursue the dual C goals. There is tremendous pressure to coordinate low-C agriculture and food security. China's food production (crop and livestock products) reached 2 Gt in 2020. Although, the tension over food security has not been fully resolved, grain imports are still as high as 140 Mt. More than 40% of livestock products for consumption depend on international trade[22]. China's food production is projected to increase from the current level (~2 Gt) to 2.3 Gt by 2050, while GHG emissions in livestock will increase from 16.7 to 19.9 $Tg \cdot yr^{-1}$ CO_2 equivalent. Thus, it is a major challenge for China's agricultural sector to reduce C emissions over the long term, while ensuring food security. This situation is different from that of developed countries and requires scientific and technological innovation.

The effects of agriculture production on Earth's ecosystems exceeds global boundaries, especially through the overuse of nitrogen fertilizers[23]. In the past 40 years, crop production has increased by 90%, nitrogen fertilizer consumption has increased by 160%, and GHG emissions from agriculture in China have doubled[24]. Nitrogen use efficiency (the fraction of crop N uptake relative to N input) in Chinese crop production is only 0.25, compared to 0.42 globally and 0.65 in North America[25]. Excessive N input has caused widespread water and air pollution across China. For example, about one-third of China's river monitoring stations and nearly two-thirds of its groundwater wells show severe nitrate pollution (> 30 $mg \cdot L^{-1}$ N)[26]. The N input will likely increase from the current level of 45–50 Tg to meet the projected demand for food production in 2050; this will lead to more severe N loss, such as NO_3^- leaching that is projected to reach 4.6 Tg (National Agricultural Green Development Seminar, 2022, China Agriculture University). The implication of this is that the Chinese agricultural sector will find it quite difficult to achieve C neutrality. Thus, agricultural green development (AGD; defined as green and low-C sustainable growth going forward) will be a priority (Fig. 1).

To achieve AGD in the context of dual C goals, it is necessary to redesign the food system from the top-down, with special consideration of food security and environmental safety (Fig. 2). Meanwhile, critical units of the food chain from the bottom-up must take measures to quantify and optimize production to meet the dual C goals and achieve a sustainable long-term future for China.

Agriculture is a sector with numerous components (e.g., irrigation, fertilization, and transportation) that has complex interactions with other sectors. For example, the industrial sector produces fertilizers, and harvested crops need the transport sector[27]. Previous studies generally emphasized a single component or process, ignoring the overall interactions. Consequently, identifying the critical component or process for agricultural C reduction is difficult. The potential for fully committing to system-level C emission reduction and soil C sequestration in agriculture is still unclear; therefore, it is of utmost importance to better understand the potential to use these methods and implement them in practice.

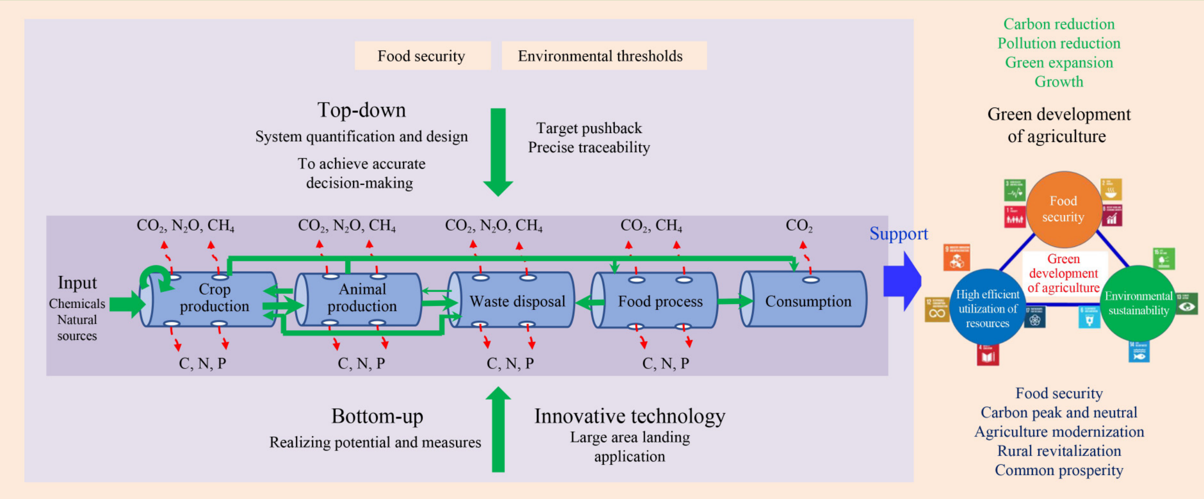

Fig. 1 Theoretical framework of agricultural green development (AGD) in China in the context of dual C goals.

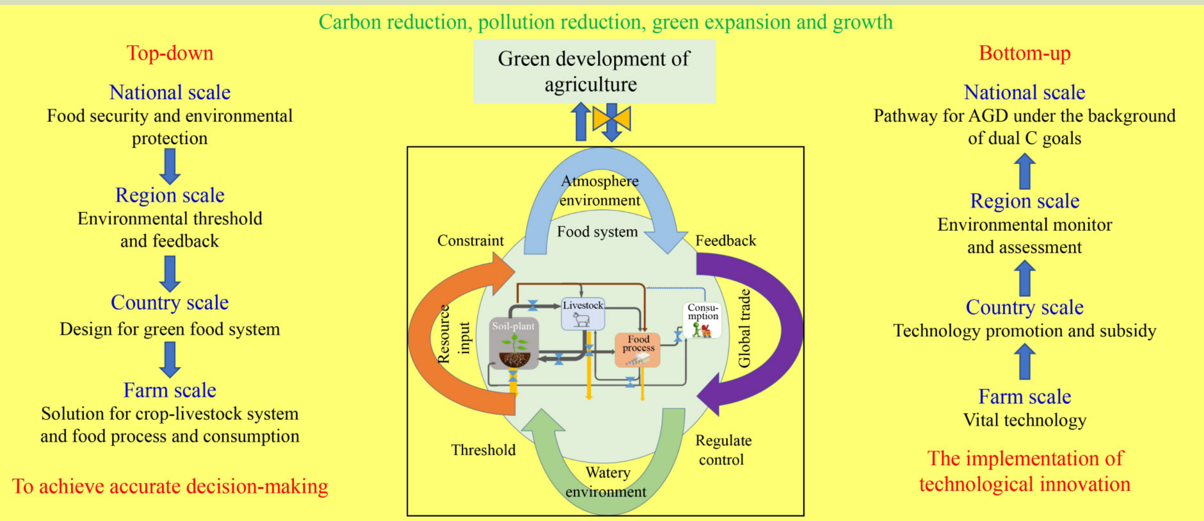

Fig. 2 The implementation pathway of agricultural green development (AGD) in China in the context of China's dual C goals.

3 TECHNOLOGICAL REALIZATION PATHWAYS

Improving key elements of crop production, including soil, fertilizer, water, and seed management, is essential to continually increase productivity[28]. First, it is important to optimize the integrated soil–crop system management technology and realize a green, high-efficiency, and low-emission technological approach based on optimized water, fertilizer, and pesticide use (Fig. 3). Second, the regional planting system should be replaced with one that promotes crop diversification, improves yield and efficiency, achieves higher C sequestration, and lowers emissions to synergistically achieve high crop yield, resource use efficiency, and environmental sustainability. Third, improvements are needed in the irrigation management of paddy rice to reduce methane and GHG emissions. Optimal management practices include replacing continuous flood irrigation with non-continuous flooding, increasing organic fertilizer application, and adopting water-saving and drought-resistant rice cultivars[29]. Fourth, the agriculture sector should develop biological regulation technology based on the rhizosphere microbial community to improve resource use efficiency. Fifth, newly enhanced-fertilizers and advanced management practices (e.g., deep

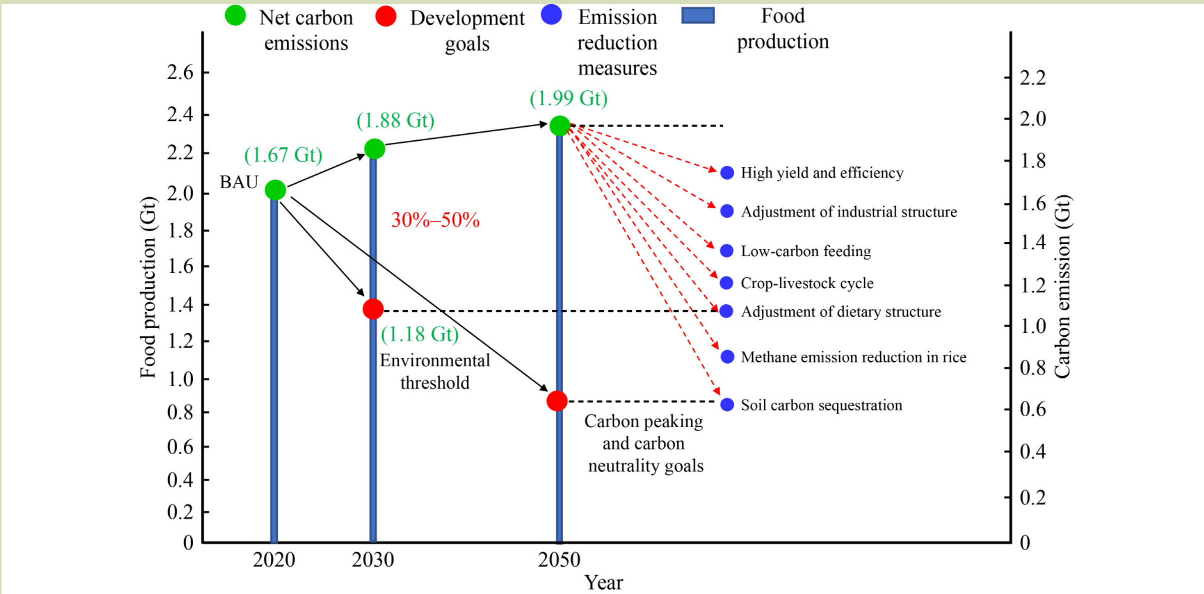

Fig. 3 Collaborative technological innovation and reduced C emissions and increased food security along the whole agricultural chain.

placement of fertilizer, drip irrigation, and conservation tillage) should be developed to reduce emissions and increase C sequestration[30,31].

With regard to soil management, first, soil C sequestration projects should be implemented that optimize manure application and straw return. This would improve agricultural waste use efficiency and increase the soil organic C content and quality. Second, conservation agriculture, such as straw mulching and no-tillage, should be implemented on a larger scale to reduce soil erosion by wind and water, increase soil fertility, and reduce straw burning and GHG emissions. Third, high-quality farmland management should be promoted, especially practices that reduce soil acidification and salinization to improve soil fertility and enhance C sequestration potential[32–34].

In addition, there is a need to concentrate on the utilization of agricultural organic waste (e.g., straw). This requires improvements in the emission reduction performance throughout the treatment and utilization of organic waste from agriculture, as well as the quality of the various bioconversion products in organic waste. For example, integrating biomass pyrolysis and an electricity generation system, coupled with commonly applied methane and N mitigation measures, can help to reduce GHG emissions throughout the crop life cycle[30,31]. This could be achieved by promoting innovative recycling agriculture technology and establishing rural recycling agriculture systems using methane and straw gasification to generate power[35]. Based on the principles of ecological agriculture, household agriculture practices (which are dictated by local conditions) could be applied to develop and recycle raw materials and waste from crop and livestock production.

4 POLICY AND OPTIONS FOR ACHIEVING C NEUTRALITY IN AGRICULTURE

At the policy level, it is important to first develop a feasible roadmap for AGD in the context of China's dual C goals to ensure food security while reducing C emissions and increasing C sequestration[31]. Second, an accountability system encouraging large-scale operators to adopt more sustainable agricultural practices and make key contributions to agricultural C emission reduction should be implemented to meet the dual C goals. Third, financial innovation is necessary; green financial services should be created to promote green policy incentives and financial credit (e.g., C accounts and C credits), thus enabling greater financial leverage to promote AGD[31]. Fourth, the development of support and guarantee systems for realizing AGD should be accelerated to improve the monitoring and mitigation of agricultural C emissions; a regional C emission-sequestration database should be established to provide data supporting AGD[36]. Finally, policymakers and the scientific community should promote China's sustainability initiative and provide guidance on green agricultural production to enhance awareness of the benefits to society of adopting low-C systems and attaining C neutrality.

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Compliance with ethics guidelines

Yulong Yin, Kai He, Zhong Chen, Yangyang Li, Fengling Ren, Zihan Wang, Yingcheng Wang, Haiqing Gong, Qichao Zhu, Jianbo Shen, Xuejun Liu, and Zhenling Cui declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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