Greenhouse gas emissions and their mitigation potential for the farming sector in Sichuan Province

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1 Project Overview

1.1 Background

Reaching carbon peak and achieving carbon neutrality are major strategic goals by China. On September 22, 2020, the Chinese government announced that the People's Republic of China will aim to have carbon dioxide (CO2) emissions peak before 2030 and strives to achieve carbon neutrality before 2060. On October 24, 2021, the Central Committee of the Communist Party of China and the State Council jointly issued a high-level policy framework which underpinned this commitment. The document titled "Action Plan for Carbon Peaking Before 2030"laid out the overall arrangements for promoting carbon peaking and proposed "Ten Major Actions for Carbon Peaking." At the same time, all provinces, autonomous regions, and municipalities directly under the Central Government are required to scientifically formulate action plans for carbon peaking in their regions and propose realistic and feasible timetables and roadmaps.

1.2 Agricultural production

As a major agriculture producing province, in 2020, Sichuan's agriculture GDP was approximately 554 billion yuan, contributing 14% to Sichuan's GDP. Sichuan has a large rural population of about 36.2 million, accounting for 43.3% of the total population. The annual sown area of grains in Sichuan is 6.3 million hectares, followed by oil crops with 1.58 million hectares. The sown area of Chinese herbal medicines is 144,000 hectares, and the sown area of vegetables and edible fungi is 1.44 million hectares. The annual grain output was 35.3 million tons. Among cash crops, the output of oil crops was 3.9 million tons, that of tobacco leaves 162,000 tons, vegetables and edible fungi 48 million tons, tea 344,000 tons, garden fruits 10.836 million tons, and the output of Chinese herbal medicines was 527,000 tons. 80% of crop straws (and 90% of rice straw) in the province were utilized for other agricultural or industrial purposes. More than 75% of the livestock and poultry manure was also utilized. The area of cultivated land using organic fertilizer has reached more than 2.3 million ha.

1.2 Agricultural production and GHG emission reduction and sequestration in Sichuan Province

As a major agriculture producing province, Sichuan Province holds an important key to reducing GHG emissions, sequestering carbon in the agricultural sector and achieving carbon neutrality. In 2020, Sichuan's agriculture GDP was approximately 554 billion yuan, contributing 14% to Sichuan's GDP. Sichuan has a large rural population of about 36.2 million, accounting for 43.3% of the total population. The annual sown area of grains in Sichuan is 6.3 million hectares, followed by oil crops with 1.58 million hectares. The sown area of Chinese herbal medicines is 144,000 hectares, and the sown area of vegetables and edible fungi is 1.44 million hectares. The annual grain output was 35.3 million tons. Among cash crops, the output of oil crops was 3.9 million tons, that of tobacco leaves 162,000 tons, vegetables and edible fungi 48 million tons, tea 344,000 tons, garden fruits 10.836 million tons, and the output of Chinese herbal medicines was 527,000 tons. 80% of crop straws (and 90% of rice straw) in the province were utilized for other agricultural or industrial purposes. More than 75% of the livestock and poultry manure was also utilized. The area of cultivated land using organic fertilizer has reached more than 2.3 million ha.

"Sichuan Province's 14th Five-Year Plan to Promote Agricultural and Rural Modernization" lays out the Province's commitment to implement the national guidance on carbon peak and carbon neutrality, carry out agricultural and rural emission reduction and carbon sequestration actions, develop green low-carbon circular agriculture, and continuously improve the carbon sink of agriculture. It requires research on the province's agricultural and rural carbon emissions measurement and carbon peaking action goals, pathways, and specific measures. Also, the "Sichuan Province Agriculture and Rural Carbon Emissions Peaking Action Plan" is to be laid out, including clear timetable and roadmap for actions and interventions.

This project focuses on the cropping sector of Sichuan Province. Based on GHG emission accounting guidelines, data integration, policy research and on-site visits, it systematically and comprehensively evaluates methane and nitrous oxide greenhouse gas emissions in the cropping sector in Sichuan Province and 21 cities and autonomous prefecture. The analysis is meant to provide a reference for Sichuan's GHG Emission Inventory and can be used to inform the formulationof an action plan that guides the province's carbon emission peaking plan. The study may also be utilized to guide carbon sequestration, and green and low-carbon development at the provincial and municipal levels in Sichuan.

2 Main challenges in reducing emissions and sequestering carbon of the cropping sector

First, expanding rice planting to ensure food security will intensify methane emissions from rice fields. Sichuan focuses on food security, the "greatest concern of the country", and strives to build a higher-level "Tianfu Granary" in the new era. Under the guidance of this goal, further increasing the rice planting area will increase the pressure to reduce methane emissions from rice fields.

Second, there is insufficient technology for the development of low-carbon agriculture.
The links involved in emission reduction and carbon sequestration in the cropping sector are complex and have a wide variety of technologies. Moreover, Sichuan's terrain, climate, soil, and farming systems are diverse. Appropriate emission reduction and carbon sequestration technologies need to be considered based on different planting environments. However, currently, Sichuan Province lacks relevant technologies and solutions to reduce carbon emission and refine emission source management.

Third, a dynamic monitoring system for carbon emissions indicators in the cropping has not yet been established.
There are many types of inputs and outputs in the crop production, and they fluctuate greatly, making the estimation parameters of carbon emissions uncertain and difficult to calculate. Conditions vary greatly in different regions of Sichuan. Carbon emissions from crops lack breakdown data classified by specific varieties and regions. The monitoring system for carbon emissions is to be established and continuously improved to accurately assess carbon emissions by region and formulate carbon reduction targets.

Fourth, the fragmentation of farmers has made agricultural low-carbon transformation more difficult.

The per capita cultivated land area in Sichuan is only 0.86 mu (1 mu = 0.067 ha), which is about 36.8% lower than the national average. Smallholder farming and the corresponding land fragmentation will continue in the foreseeable future. Smallholders' production behavior is highly uncertain and their ability to deal with various risks is low. In addition, the overall technical level of Sichuan's rural labor force is not high, and the service provision system is inadequate. Used to traditional cultivation method, farmers are generally not receptive of carbon reduction or sequestration practices.

3 Policy recommendations for reducing GHG emissions in crop farming

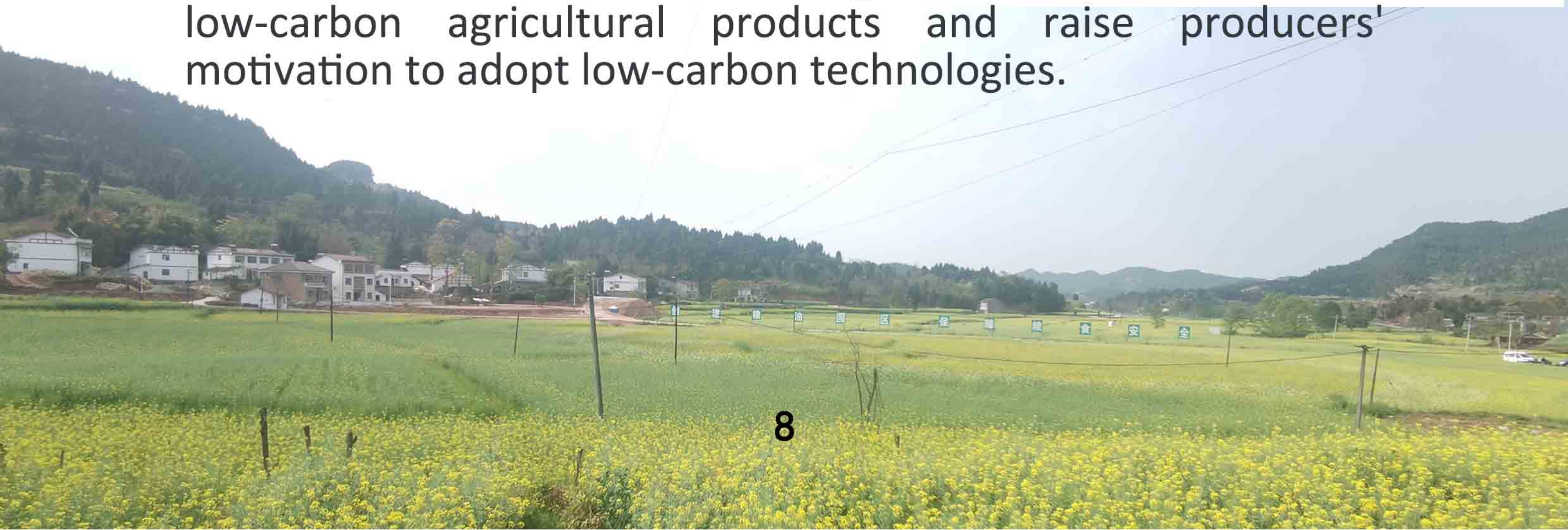
Based on the above, the following actions are recommended as priorities for action to address the challenges faced by the cropping sector, reduce GHG emissions, and sequester carbon while ensuring food security in the province:

The first is to adopt a "Greater Food" approach a of green, low-carbon and circular development. Going forward, Sichuan should expand the sources and types of food, make good use of its own resources, actively seek calories and protein from cultivated land, grasslands, and forests, develop plant, animal, and microbial food resources in an all-round way. Balance the supply and demand of various types of food, ensure the production, quality, and diversification of food, promote the efficient use and orderly circulation of natural resources, and achieve ecological low-carbon and sustainable development of food production.

The second is to increase the research, development and promotion of simplified, integrated, and standardized emission reduction and carbon sequestration technologies. Special funds should be created to support basic and long-term scientific research on technologies for reducing methane emissions from rice fields and nitrous oxide emissions from agricultural lands. In view of the characteristics of small-scale farmers as the main producers in Sichuan, it is recommended to carry out regionally targeted, low-cost, and easy-to-promote technologies that resonate well with farmers. Methane emission reduction efforts in rice fields should focus on implementing technology solutions that improve water management in rice fields, optimize straw utilization, change rice farming patterns in winter paddy fields, and select high-yield and low-emission rice varieties, without jeopardizing food security. Efforts on reducing nitrous oxide in agricultural lands should focus on implementing technology solutions that rationally reduce nitrogen to control surplus, use high-efficiency nitrogen fertilizers/bacteria, improve nitrogen application methods, and plant nitrogen-fixing crops. It is also advisable to support low-carbon technology in the cropping sector and build several large-scale application demonstration projects for green and low-carbon technologies.

The third is to establish a long-term dynamic monitoring system for carbon emissions in the cropping sector. Indicators can help monitor, verify and report carbon emissions in the cropping sector. This will enable stakeholders to systematically formulate accounting standards and clarify emission patterns and key parameters for different climates, soils, management methods and planting types. This can be achieved by setting up long-term monitoring sites. We also suggest to establish a digital carbon emission management platform and strengthen the verification of emissions data from the cropping sector and compare and verify data reported by farmers and enterprises with the country's provincial emission inventories, scientific research, satellite remote sensing, ground observation data, etc., to enhance the accuracy of monitoring.

The fourth is to improve extension systems and provide targeted incentives for low-carbon production. This involves the establishment of an extension service system targeted to low-carbon production, training of professional agricultural service operators, and by linking emission reduction practices with carbon sequestration technologies. Good low-carbon agricultural practices should be systematically promoted and supported by specially designed incentive mechanisms, e.g. subsidized technologies that are green, environmentally friendly, have good emission reduction effects and are easy to monitor and verify, such as intermittent irrigation, high-efficiency fertilizers, side-deep fertilization, and returning mature straw to the fields. New innovative business models that target low-carbon production should be supported financially and through the provision of appropriate training, including on entrepreneurial skills. The establishment of labels for low-carbon, zero-carbon, or carbon-neutral agricultural products would increase the ecological and economic value of low-carbon agricultural products and raise producers' motivation to adopt low-carbon technologies.



4 Climate-smart agriculture technology path

Climate-smart agricultural production technology has the following three characteristics:

1) It can continuously increase agricultural output, income, and production capacity.

2) It can build or improve climate change adaptation capabilities and climate resilience.

3) It can reduce or avoid GHG emissions.

For methane and nitrous oxide,it is important to analyze and present the various existing emission reduction technologies and good practices, evaluate their emission reduction effects, associated costs, applicability, and co-benefits or risks, and select technologies suitable for the cropping sector in Sichuan Province.

4.1 Technology pathways for methane emission reduction in rice fields

Rice cultivation in Sichuan Province is mainly based on mid-season rice and winter paddy fields. The crop rotation methods are rice-wheat/rapeseed, rice-cash crops, and rice-winter fallow. Based on our analysis, the technology path for methane emission reduction in rice fields can be prioritized for promotion. The findings are summarized into four categories by priority level, namely 1) improving rice field water management, 2) optimizing straw utilization methods, 3) changing winter paddy field rice farming patterns, and 4) selecting high-yield and low-emission rice varieties.

(1) Improving rice field water management

Improving water management in rice fields presents the most important climate-smart technical strategy as it can significantly reduce methane emissions in rice fields while maintaining stable production and improving water resource utilization efficiency. It is simple and easy to implement and should follow either of the following two technical strategies:

a) mid-term drying and intermittent irrigation technology.

Rice has different water demand patterns, which are either characterized by flooding in the early growth period, drying in the mid-term, alternate drying and wetting in the later period, and drying at maturity. Draining and drying the rice field at the end of tillering can increase the soil redox potential, prevent excessive reduction of the soil from inhibiting root growth, promote the development and growth of the root system, and inhibit ineffective tillering, which is beneficial to improving rice yields and nitrogen fertilizer use efficiency, thereby reducing methane emissions. The use of this technology requires good water source conditions as a guarantee, and it can be drained and irrigated. Therefore, the plain rice cultivation areas and hilly rice cultivation areas with good water source conditions in Sichuan Province can be widely promoted.

b) The second is water-saving irrigation technology.

This strategy is based on mid-term drying and intermittent irrigation, and further controls the amount of irrigation according to the water demand characteristics of rice, generally including "thin-shallow-wet-dry" irrigation", " water-saving and oxide-increasing irrigation ", "thin dew irrigation", " wet irrigation", etc.. During a specific period of rice growth and development, the thin water layer on the field surface, no water or the soil water content is lower than the saturated water content, greatly improving the soil aeration condition, which not only promotes the oxidation of methane, but can also inhibit the production of methane to a certain extent and has a significant effect on reducing methane emissions in rice fields.

(2) Optimizing straw utilization methods

Optimizing the use of straw can promote nutrient recycling in the rice field ecosystem, significantly reducing the increase in methane emissions caused by direct return of straw to the field, and can synergistically achieve stable rice yield growth, improve soil carbon sink capacity, and resource utilization efficiency, including the following two technology strategies.

■ **The first is the technology of decomposing straw, stacking, and retting it to the field, returning biogas slurry and residue to the field, and returning it to the field in the dry season.** The fresh straw is fully decomposed and stacked or fermented to produce biogas before returning it to the field, and the rice fields are dried during the non-rice growing season of the paddy and drought rotation. Returning it to the fields under conditions can effectively avoid the increase in methane emissions caused by the carbon decomposition of fresh straw in the flooded anaerobic environment of rice fields, promote aerobic decomposition, and reduce methane emissions.

■ **The second strategy is straw off-field utilization technology,** which collects straw and uses it as base material (e.g., for producing mushrooms), energy (fuel for power generation and heating) or feed (feeding livestock) to reduce methane emissions caused by returning straw to the field.

(3) Changing the rice farming model in winter paddy fields

Winter paddy fields are a special feature of rice farming in Sichuan Province and are of positive significance to ensuring food supply. The province has many winter paddy fields that are flooded all year round. Such rice fields have high methane emissions. Changing the rice farming model in winter paddy fields can significantly reduce methane emissions caused by long-term flooding of rice fields. We suggest the following two technology strategies: **a) The first is the film-covered water-saving cultivation technology for winter paddy fields,** which involves film mulching as the core and integrates open-box ridge cultivation, box-furrow water-saving irrigation and seedling transplanting. It can increase rice production while significantly reducing methane emissions and improving water use efficiency. **b) The second strategy is to strengthen farmland water conservancy construction, increase irrigation area,** transform perennial winter paddy fields into paddy and dry crop rotation according to local conditions, and plant wheat, rape, vegetables, green manure, and other dryland crops in winter, which will not only significantly reduce methane emissions from winter paddy fields, but also increase income in one season.

(4) Selecting high-yield and low-emission rice varietiess

There are significant differences in methane emissions across the different rice varieties. Choosing high-yielding and low-methane-emitting varieties can achieve synergy in reducing emissions and increasing yields. We suggest the following two technology strategies. **a) The first one is to choose water-saving and drought-resistant rice varieties.** Planting such rice varieties in water-scarce areas, combined with water-saving irrigation in rice fields, can effectively reduce methane emissions. **b) The second strategy is to screen and plant rice varieties with high yield and low methane emission potential.** Varieties with a high harvest index, large ears and grain weight, and strong stem oxygen transmission capacity have the potential to achieve high yields and emission reductions.

4.2 Technology pathways for reducing nitrous oxide emissions from farmland

Sichuan Province has diverse crop types, and its output of grain crops, oil crops, and cash crops (vegetables, fruits, medicinal materials, etc.) ranks among the top in the country. Based on the emission reduction technologies derived from the above integrated analysis and comprehensively considering the emission reduction effect, cost-benefit, degree of promotion and applicability, the nitrous oxide emission reduction technology for agricultural land in Sichuan Province can be summarized into four categories according to priority and ease of adoption. **These are 1) reasonable nitrogen reduction and surplus control, 2) using high-efficiency nitrogen fertilizers/ bacteria, 3) improving nitrogen application methods, and 4) planting nitrogen-fixing crops.**

(1) Reasonable nitrogen reduction and surplus control

Excessive application of nitrogen fertilizers results in large amounts of nitrous oxide emissions from agricultural lands. Scientific and reasonable determination of nitrogen application amounts and precise nitrogen reduction are the most effective means to reduce such emissions. In order to quickly reduce nitrous oxide emissions, it is advisable that farmers strengthen soil testing, determine nitrogen fertilizer dosages based on scientific evidence, soil nitrogen supply and crop nitrogen demand, reduce nitrogen reasonably, and control excessive nitrogen surplus in agricultural lands, especially for fruits, vegetables, tea and other cash crops.

(2) Using high-efficiency nitrogen fertilizers/inoculants

High-efficiency nitrogen fertilizers can provide nitrogen nutrition stably and continuously, improve crop nitrogen utilization efficiency and yields, and reduce environmental pollution and GHG emissions. Microbial inoculants can activate soil, promote the decomposition of organic materials, enhance nutrient supply capacity, increase crop yields, promote nutrient recycling and reduce environmental load. We suggest the following two technology strategies.

a) The first one is to use slow-controlled release fertilizers and synergistic fertilizers with added nitrification inhibitors/ urease inhibitors which are suitable for various types of crops and can be applied in reduced amounts according to crop types and soil conditions to further reduce input costs.

b) The second strategy is to use multifunctional compound inoculants, nitrogen-fixing microorganisms/denitrifying microorganisms inoculants and biofertilizers, mainly for cash crops, to help achieve synergy in improving quality and efficiency and reducing emissions and carbon sequestration.

(3) Improving nitrogen application methods

During the application of nitrogen fertilizer, changing the location and frequency of fertilization, optimizing the fertilization formula and proportion, and changing the fertilization method to achieve water-fertilizer coupling can effectively improve crop yields and nitrogen fertilizer use efficiency, and reduce environmental pollution and GHG emissions caused by nitrogen fertilizer loss. Improving nitrogen application methods includes the following three technology strategies.

a) First, adjust the nitrogen ratio of base fertilizer to a relatively lower level and then move nitrogen fertilizers to the critical period when crops need nitrogen to avoid excess nitrogen loss caused by high nitrogen application in the early stages of crop growth. This will improve nitrogen utilization efficiency, and effectively reduce nitrous oxide emissions.

b) The second one is deep application of chemical fertilizers and simultaneous sowing of seeds and application of fertilizers. The technology is often adopted for farmland with mechanized sowing. In orchards, tea gardens and vegetable fields, we can apply furrow application, hole application, ring application, and deep application of fertilizers according to local conditions to promote crop root systems. The absorption of nitrogen can effectively reduce nitrous oxide emissions and ammonia volatilization.

c) The third one is water-fertilizer integration/foliar fertilizer technology. This technology requires a certain amount of investment and is mainly aimed at cash crops with higher premiums. It can achieve water-fertilizer coupling, save water and fertilizer, improve quality and efficiency, and can collaboratively achieve nitrous oxide reduction.

(4) Planting nitrogen-fixing crops

Planting nitrogen-fixing crops such as grain and bean rotation/intercropping and green manure can increase the amount of nitrogen fixed in the agricultural land ecosystem, thereby reducing the input of chemical nitrogen fertilizers, effectively reducing nitrous oxide emissions, and improving resource utilization efficiency, economic benefits, soil fertility and biodiversity. This is a nature-based solution that can be implemented at low or no cost. Growing nitrogen-fixing crops involves the following two technology strategies.

a) The first is grain and bean rotation/intercropping, which uses corn-soybean strip compound planting, rice (corn)-soybean-rapeseed rotation and other technologies to achieve reduced application of chemical fertilizers and pesticides, increase production and income, and be green and low-carbon.

b) The second strategy is to plant green manure cover crops. Plant leguminous green manure, such as alfalfa, white clover, peas/broad beans, wild rice seeds, milkvetch, etc., during the fallow season of farmland and orchards to cover the exposed soil and achieve a combination of land use and land use. It can reduce fertilizer nitrogen input and thereby reduce nitrous oxide emissions.

4.3. Summary

There are several technology solutions that can effectively address and reduce methane emissions in rice fields. These include improving rice field water management, optimizing straw utilization, changing winter paddy field rice farming patterns, and selecting high-yield and low-emission rice varieties. Sichuan Province can achieve a methane emission reduction while ensuring stable and increased rice production and improving water use efficiency.

Nitrous oxide emissions in agricultural land can also significantly be reduced through the aforementioned technologies and techniques. Sichuan Province could achieve a reduction of nitrous oxide emissions from agricultural land while ensuring stable and increased grain production and improving nitrogen fertilizer utilization.

Summing methane and nitrous oxide all together, the implementation of the above-mentioned emission reduction technology paths, Sichuan Province can achieve a greenhouse gas emission reduction. This scenario would have multiple economic and ecological benefits such as reducing fertilizer and pesticides and improving climate resilience and biodiversity. This report is based on the concept of climate-smart agriculture and proposes a technology path for emission reduction in the cropping sector based on the actual situation of Sichuan's agricultural production. It can provide a scientific reference for the green, low-carbon and high-quality development of agriculture in Sichuan Province.

5 Policy recommendations on technology pathways for emission reduction in the cropping sector

To cope with the challenges and possible risks faced by the transformation to low-carbon farming, the following three suggestions are put forward from a technical perspective:

First, we need to optimize and integrate existing methane and nitrous oxide emission reduction technologies, and to build a simple, low-cost, implementable, and easy-to-promote emission reduction package for different crop types, production areas, and topographic features in Sichuan. We will carry out pilot trials to create a low-carbon model for the cropping sector, and guide large-scale agricultural enterprises, production cooperatives and large growers to build emission reduction technology application and demonstration platforms, play a role model and lead, and then drive small-scale farmers to adopt low-carbon production methods.

Second, we need to strengthen long-term and basic scientific research for methane emissions from rice fields and nitrous oxide emissions from agricultural land, and increase the research and development of innovative and breakthrough emission reduction technologies, including the cultivation of new low-emission and high-yielding crop varieties and more efficient fertilizers , biological nitrogen and carbon fixation technology, low-cost biochar preparation technology, plantation industry waste pyrolysis, carbon gas co-generation technology, and so on. Meanwhile, we need to strengthen the integrated research and development of ecological and low-carbon production models, which are nature solutions based. This will help build the technology pipeline for achieving carbon neutrality by 2060.

Lastly, we need to build an emission monitoring, reporting, and verification system for the cropping sector, formulate greenhouse gas emission observation norms and standards, clarify localized emission factors and key parameters for methane in rice fields and nitrous oxide in agricultural lands, and establish emissions and key parameters based on specific locations. It is necessary to develop and improve the emission reduction methodology for the cropping sector suitable for Sichuan, promote the inclusion of a carbon emission reduction accounting certification system, and achieve economic compensation for agricultural emission reductions through market mechanisms and ecological compensation mechanisms, thereby advancing agricultural development and farmers' incomes.

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