# Green Food Development in China

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Contributor: Xuexian Li

China feeds approximately 22% of the global population with only 7% of the global arable land because of its surprising success in intensive agriculture. This outstanding achievement is partially overshadowed by agriculture-related large-scale environmental pollution across the nation. To ensure nutrition security and environmental sustainability, China proposed the Green Food Strategy in the 1990s and set up a specialized management agency, the China Green Food Development Center, with a monitoring network for policy and standard creation, brand authorization, and product inspection.

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## 1. Introduction

A leading challenge of the 21st century is to ensure global food security on a socioeconomically sustainable basis; annual grain production needs to increase by approximately 580 million tons (MT) by 2030—a 2% increase per year—in order to meet the grain demands of the rapidly growing population[1]. With 22% of the world's population depending on only 7% of the cultivated land [2], the total annual grain production in China has increased from 280 to 617 million tons (~120%), and the average grain yield has increased from 2949 to 6081 kg $ha^{-1}$ (~106%) over the last four decades (1980–2018)[3][4]. Such achievements in grain production rely heavily on high levels of resource inputs. The increase in the application of chemical nitrogen (N) fertilizers, from 9.34 to 20.65 million tons (National Bureau of Statistics of China), has resulted in a lower overall N use efficiency of 0.25, compared with 0.42 in developed countries[5]. If an excessive amount of synthetic N enters the surrounding environment, it causes soil acidification and the intensification of greenhouse gas emissions, N deposition, and the eutrophication of surface water[5][6][7] Soil acidification in southern China significantly stimulates the bioavailability of heavy metals, i.e., Cd and Mn, and certain levels of heavy metals are unintentionally included in composts and phosphate fertilizers[8]. Almost 20% of the farmland in China has been polluted by heavy metals, especially cadmium (Cd), nickel (Ni), and arsenic (As)[9], and the related food contamination has become an increasingly serious agricultural and social issue[10]. The overuse of pesticides is another challenge for improving food quality; the intensity of pesticide use increased from 5.83 kg/ha in 1990 to 13.07 kg/ha in 2018, with an average annual growth of 4.28%[3]. The public policy "zero growth of chemical fertilizer and pesticide use by 2020" was therefore initiated in 2015 in order to sustain agriculture development in China.[11]

Green food was first introduced in China by the Ministry of Agriculture (MOA) in 1990, and it primarily refers to a full range of edible plants, animals, fungal raw materials, value-added processed products, and condiments. According to the principle of sustainable development, standard operational protocols apply to the full industry chain, including the production, processing, packing, storage, and transportation of green foods for farm-to-fork quality control and the efficient utilization of resources, as designed by the China Green Food Development Center (CGFDC). With strict regulations and regular inspection, green food dramatically reduces resource inputs, i.e., chemical fertilizers, pesticides, and related additives; disseminates new technologies; improves environmental and food quality; increases farmers' earnings[11]. Over the past three decades, green food has undergone exponential development in terms of the cultivation area, number of products and companies, and domestic and international markets and sales. Herein, we systematically summarize the regulation and development of the green food industry, as well as its broad significance and challenges.

## 2. Agricultural and Environmental Advantages of Green Food

Green food has brought about far-reaching environmental, economic, and social impacts with its rapid development across the mainland over the past three decades. Here, we consider how a 50% cut of chemical nitrogen fertilizers and the supplementation of organic fertilizers (N fertilization guide for green food) affect crop production and environmental protection (Table S2).

### 2.1. Crop Yield and Quality

Numerous studies have suggested that less than 50% of the N fertilizers that are applied are absorbed by crops, and a large percentage of the remaining active N goes into the soil, water, or air, causing severe environmental damage[12] [19]. In the North China Plain and the Taihu Region, a 30–60% decrease in chemical N fertilizers does not affect the yields of rice, wheat, or maize[13]. A more recent meta-analysis has revealed that the substitution of 50–75% of chemical N fertilizers with livestock manure improves the crop yield by 12.7% [14]. In a 19-year long-term field experiment in China, using a similar 50% replacement strategy, the crop yield was improved and yield variability was reduced; these results are also supported by experiments with other crops[15] [22]. Beyond annual crops, apple yields can increase from 31.5 to 42.1 t/ha when supplied with mixed N (50% chemical N and 50% swine manure); more importantly, a combinatorial N supply significantly improves the fruit quality, as indicated by the higher values for the sugar/acid ratio, concentrations of vitamin C and soluble solids, and firmness[16]. Green cucumber grown in this manner is free from environmental contamination and is safer for human consumption compared with local farmers' cucumber[17].

### 2.2. Environmental Consequences

The application of organic fertilizers improves the organic matter content, soil microbial activities, and water and nutrient holding capacities, while reducing water contamination[22][23][24][25]. Green food favors organic fertilizers because of its greater nutrient-use efficiency, less nutrient leaching and volatilization, and lower environmental costs in different agroecosystems, as supported by numerous studies with a comparable N regime[25][18][19][20][21][26]. The mixed and balanced organic and inorganic N supply promotes soil carbon sequestration in the rice–wheat rotation system[27], and considerably reduces $N_2O$ emissions compared with inorganic N dominant treatment[28].

Therefore, the green food model may serve as a win–win strategy for sustainable environmental and economic development.

## 3. Potential and Large-Scale Impact of Green Food Farming Scenario

The potential larger-scale impact of the green food industry in China has been projected through a scenario analysis. For instance, the large-scale adaptation of the "Green Food Fertilizer Application Guideline," namely, reducing chemical N fertilizers by 50% so that the proportion of green food in China increases to 20%, would determine the potential N fertilizer and emission reduction. In this simulation, the chemical N fertilizer (N fer) input of conventional farming was based on a previous study—a database constructed by Zhang et al. from a national survey of 6.6 million producers covering 54 crops in China, representing >95% of the cropland of China, which were categorized into cereals (133 kg N/ha), fruits (429 kg N/ha), vegetables (275 kg N/ha), and others (132 kg N/ha) [29]. The reduction of N consumption was estimated based on reducing chemical N fertilizers by 50% compared with conventional farming on the same cultivated area. The emission factors/models of nitrate ($NO_3^-$–N) leaching, ammonia ($NH_3$–N) volatilization, and nitrous oxide ($N_2O$–N) emissions were calculated using exponential or linear models developed by Wang et al. for wheat and maize[30], by Cui et al. for rice[31], and by Wang et al. for vegetables[32]. For fruits, it was assumed that they have similar N losses as vegetables.

Based on the scenario analysis, with the green food standard, chemical N fertilizer use would be reduced by 2.2. MT (1.33 MT for cereals, 0.24 MT for vegetables, 0.25 MT for fruits, and 0.34 MT for other crops; Figure 7). The estimated $NH_3$ emissions would be reduced by 0.17 MT, the $N_2O$ emissions would be reduced by 0.01 MT, and $NO_3^-$–N leaching would be reduced by 0.14 MT. If the proposition of the green food industry reached the predicted 20%, chemical N fertilizer use would be reduced by 5.53 MT; the emissions of $NH_3$ and $N_2O$ would be reduced by 0.40 MT and 0.03 MT, respectively; $NO_3^-$–N leaching would be reduced by 0.33 MT. The green food industry has the ability of achieving remarkable reductions in terms of chemical N use, and developing green food is an effective way to reduce the fertilizer N input and to decrease environmental pollution. Nevertheless, because nitrogen loss is only calculated by chemical N reduction, it is currently quite difficult to obtain the organic fertilizer information, which is also a major source of emissions, and needs greater investigation in order to support further analysis. In addition, future research needs to recognize the effects across the full food system in order to investigate green food industry effects, such as health, environmental, social, and economic effects.

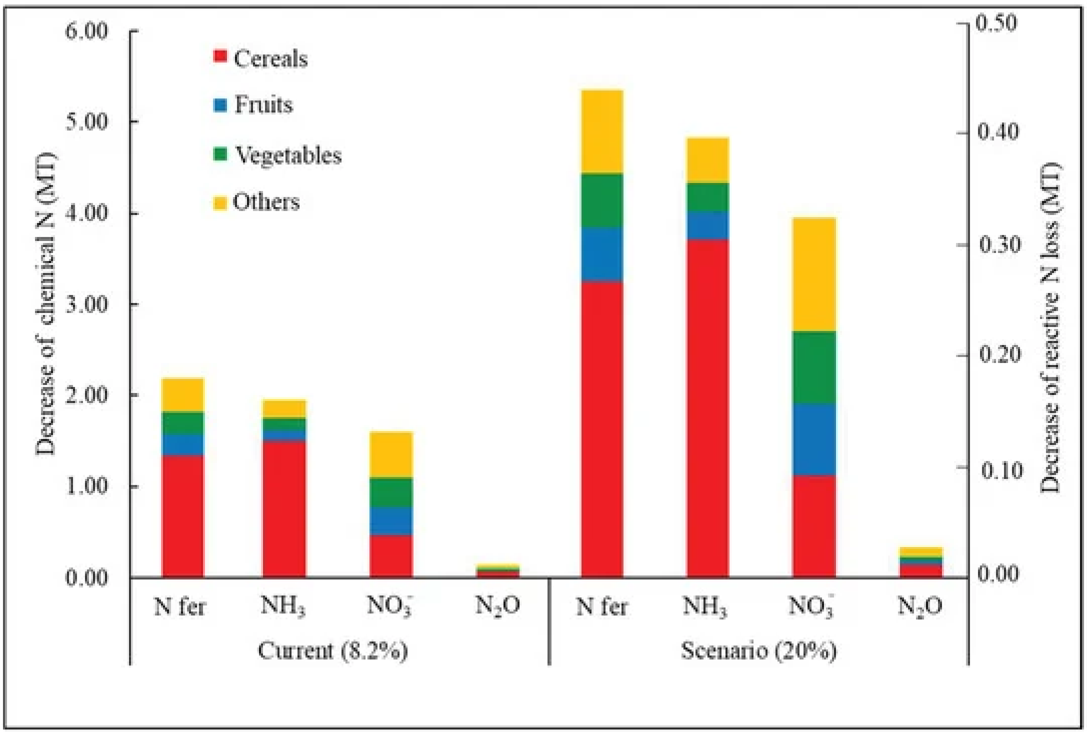


**Figure 7.** Achievable reduction in chemical N input (N fer), ammonia volatilization ($NH_3$), nitrate leaching ($NO_3^-$), and nitrous oxide emission ($N_2O$) if the proportion of green food in China increases to 20%.

While N fertilizer is excessively overused in China, sustainable agriculture has become a priority for China. China released the “action to achieve zero growth of chemical fertilizer use by 2020” policy in order to achieve zero growth for chemical fertilizer use for principal crops by 2020[29]. By 2019, 83% of the provinces reached a negative three-year average annual growth of fertilizer use, showing the potential for successfully achieving this policy[33]. Nevertheless, China’s agriculture still has a long way to go in facing the challenges of further enhancing agricultural productivity while minimizing environmental impacts. Green food is a sustainable and environmentally friendly approach, as its limited use of chemical inputs can considerably reduce environment-related concerns. Therefore, shifting from intensive conventional agriculture toward green food farming at a large scale is an effective way to realize sustainable development in China.

In addition to mitigation of environmental pollution, shifting from conventional to green food-like farming system has the potential to improve soil health by improving its physical, chemical and biological properties[34][35][36][37]. Sustainable soil health depends on the application of carbon-rich amendments that support the biological processes, which are the central foundations of healthy soil. Additionally, systemic reduction of chemical nitrogen, according to the green food rule, prevents its overuse by small-hold farmers and better balances crop nutrition, improving the quality of agricultural commodities, i.e., increasing the sugar/acid ratio of apple and grape[16][38]. It helps prepare farms and people to be more resilient to climate change; primarily, the addition of organic fertilizers improves water use efficiency, consequently, resistance to risky weather, and ultimately lowers the chances of crop failure. Pesticides and heavy metals are also critical substances under regulation of green food, however, more data and field experiments are required for in-depth quantitative analysis in the future. In brief, large-scale expansion of green food farming has promising potential to produce safe and nutritious food, improve soil fertility and quality, and eventually uplift the living standard of people on a sustainable basis.

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