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Adapting to climate change on the farm: Experiences of small-scale ecological farmers in two regions of China

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Abstract

While ecological practices are widely recognized as effective strategies for addressing climate change, their adoption among smallholders is significantly influenced by the experiences of early adopters such as small-scale ecological farmers. Despite this important factor in adoption, few empirical studies have examined how small-scale ecological farmers experience climate change and evaluate the effectiveness of their ecological approaches. Drawing on data from in-depth interviews, farm visits and surveys with 28 ecological farmers in China, we develop an integrative analytical framework that uses farmers' own narratives to examine how they perceive, are impacted by, and respond to climate change at the farm level. We found that beyond direct impacts on crop yield and quality, ecological farm productivity was undermined as climate shocks disrupt agroecosystems, damage farm facilities, and pose health risks to farm workers. In response, farmers apply diverse ecological practices alongside socio-economic measures to build resilience. While the paper demonstrates the adaptive

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value of ecological practices, it also reveals that their broader and successful adoption among smallholders is contingent upon overcoming substantial economic, social and institutional barriers. The study highlights the potential of bottom-up, farmer-led initiatives and advocates for targeted policies and services tailored specifically to the needs of ecological farmers.

Keywords
climate change, adaptation, smallholders, ecological farmers, China

> *Neither flood nor drought can stop a good peasant from farming.*
> —Hsun Tze (c. 313-238 BCE)

Introduction

Climate change poses increasing challenges to agriculture, with small-scale producers among the most vulnerable (Cohn et al., 2017; Morton, 2007; Pörter et al., 2022; Touch et al., 2024). Smallholders have been directly impacted in multiple ways, including reduced crop yields, damaged infrastructure, heightened harm from pests and disease, water scarcity, diminished income and threats to food security (Harvey et al., 2018; Ricart et al., 2023; Tofu et al., 2022). China, where the average annual surface temperature has risen at nearly twice the global average since 1951 due to its geographic conditions and land use changes (Stanway, 2022), is particularly at risk. The large number of smallholders that dominate the agricultural sector in China makes the country more vulnerable to climate change due to their reliance on natural ecosystems and limited adaptive capacity caused by constrained economic resources, inadequate infrastructure, and limited access to information and climate awareness (Morton, 2007; Xu et al., 2020). Despite their vulnerability, to cope with climate change smallholders develop adaptive strategies, ranging from crop diversification to altered planting schedules (Khanal et al., 2020; Moore & Lobell, 2014).

As most Chinese farmers are smallholders, their response to climate change shapes their livelihoods and China's overall agricultural productivity. Organic farming and agroecology, which share similar ecological principles, are considered by many scholars promising strategies to help farmers build climate resilient agroecosystems (Altieri et al., 2015; Dittmer et al., 2023; Migliorini & Wezel, 2017; Scialabba & Müller-Lindenlauf, 2010). Because of China's agricultural conditions, adopting an ecological approach offers significant benefits. Unfortunately, China's policies on climate change adaptation tend to favor large-scale technical solutions targeted at crop productivity (Rogers, 2016), although the excessive use of chemical inputs in conventional farming has depleted resources, degraded the environment (S. Li et al., 2019; Norse & Ju, 2015), and exacerbated climate change through increased greenhouse gas emissions due to chemical inputs (J. Chen et al., 2022).

Despite the increasing research on climate change and on smallholders in China and beyond, empirical studies on small-scale ecological farmer experiences and coping strategies remain scarce. This gap is particularly noticeable with the rise of small-scale ecological farms in the past two decades, driven by the growing middle- and upper-class consumers seeking risk-free food and distrusting organic labels (Scott et al., 2014, 2018). China had 6,308 certified organic producers in 2019 (Willer et al., 2021, p. 213); by 2023, the total area of certified organic farmland exceeded four million acres, ranking China fourth globally (Xiao, 2024). Lacking third-party certification, many organic farms remain invisible in official statistics so that it is difficult to estimate the number of small ecological farms. Zhong et al. (2022) estimates that there are over 1,000 small-scale organic and community-supported farms in China, operating on a model in which consumers share both the risks and benefits of food production by subscribing directly to farm produce.

Although the number of small-scale ecological farmers is limited, investigating this distinctive group offers several valuable insights into how their farming practices are adapting to climate change and how such approaches might be scaled across the broader smallholder population. First, ecological farmers operate without synthetic chemicals, demonstrating the efficacy of ecological practices. Second, unlike subsistence farmers, they are entrepreneurial, proactively employing ecological measures to balance ecological and economic viability under the pressures of climate change. Understanding their experiences can inform policies to enhance smallholder sustainability and support a broader transition toward resilient agriculture. Overall, this research aims to deepen the understanding of whether and how ecological farming can be a sustainable and economically viable pathway for smallholders in China and beyond when facing climatic challenges. China's vast smallholder base and its heighted exposure to climate change impacts make it a critical case. Insights from China are relevant to other countries with similar agrarian structures facing growing climate risks.

The following sections of this paper are structured as follows: we first review relevant literature about climate change and small farms. We then present our research methods, followed by an analysis of respondent profiles, climate impacts, and adaptive practices. We compare ecological farms to conventional farms, and offer recommendations for future research and policy to promote the broader adoption of ecological farming in China.

Farmers' Perceptions of Climate Change, Adaptation, and Barriers

To understand farmers' adoption of adaptation measures, studies on climate change perception and adaptation often apply the Protection Motivation Theory, which asserts that perceptions of severity, ability to withstand the impacts, and internal barriers significantly correlate with adaptation intentions (Ghanian et al., 2020; Keshavarz & Karami, 2016). Across diverse geographies, many studies on climate change adaptation in agriculture identify perception as a crucial factor, often considered the initial step in the adaptation process (Bohensky et al., 2013; Maddison, 2007). However, farmers' awareness of climate change varies significantly in developing countries (Harmer & Rahman, 2014). Smallholders commonly perceive climate change through increased temperatures, unpredictable monsoons, and its impacts on yields, pests, food security, and their livelihoods (Funk et al., 2020; Harvey et al., 2018; Kom et al., 2020). Recent studies have demonstrated that Chinese smallholders are acutely aware of climate change and its adverse impacts (Gao et al., 2022; Pickson & He, 2021), providing a valuable opportunity for studying climate adaptation. Little is known, however, about how ecological farmers perceive these changes.

Adaptation to climate change, like perception, has also been widely studied. Adaptation means adjustments made in processes, practices, or structures within ecological, social, and economic systems in response to climate change (McCarthy et al., 2001). Recognizing that the agricultural system is an artificial construct that incorporates elements of both natural and social systems (McConnell & Dillon, 1997), farmers' adaptation to climate change can be categorized into two types. The first involves adaptations targeting the natural elements within the agroecosystem, such as soil, water resources, crops, and livestock, and aiming to address the direct or anticipated impacts of climate change on agricultural production. The second focuses on the broader social-economic dimensions of agriculture, such as access to extension services, income diversification, and the adoption of insurance schemes, which aim to build resilience against wider systemic challenges.

Farmers are adapting to climate change by adjusting both natural agroecosystem elements and broader socio-economic factors. Strategies include crop diversification, climate-resilient varieties, altered planting dates, and improved soil and water management (Magesa et al., 2023). Livestock and fish farming adaptations, such as improved breeding and water harvesting, are also prominent (Onyeneke et al., 2019). However, current strategies may fall short in more extreme future climate scenarios, indicating the need for transformative measures like improved infrastructure, crop insurance, and livelihood diversification (Magesa et al., 2023).

For the smallholder population in general, studies in Pakistan, Ethiopia, Nepal and Kenya have shown adaptive strategies to cope with climate change, despite limited resources in those regions. These include adjusting fertilizer use, crop types and varieties, planting schedules, and irrigation practices (Abid et al., 2015; Belay et al., 2017; Karki et al., 2020; Khan et al., 2020; Ogola & Ouko, 2021). Ecological approaches, such as intercropping, crop rotation, soil amendment practices, water conservation, and agroforestry, are also common in Malawi, the Andes, Ethiopia, Bolivia, and Kenya (Ballesteros & Isaza, 2021; Bezner Kerr et al., 2019; Gebrehiwot & Van Der Veen, 2013; Jacobi et al., 2015; Muriithi et al., 2021; Ricart et al., 2023; Sedebo et al., 2021). Besides these major adaptations, smallholders in Nepal are also resorting to supplementary strategies such as the use of greenhouses, diversification of income, and migration (Karki et al., 2020).

Similarly, Chinese farmers employ a range of adaptation methods that span conventional farming to ecological practices, such as crop diversifying, increasing chemical inputs, adjusting planting and harvesting dates, changing crop varieties, and enhancing irrigation infrastructure (H. Chen et al., 2014; C. Li et al., 2013). More sustainable approaches, such as soil and water conservation and agroforestry, have been adopted in tropical agriculture in Hainan (Gao et al., 2022) and across the Loess Plateau of China (Alhassan et al., 2021), while conservation tillage and intercropping are prevalent in Fujian Province (Sattar et al., 2023). Local governments support smallholders with extension services, financial subsidies, and production inputs to combat climate challenges (H. Chen et al., 2014).

Beyond documenting various adaptation measures, researchers have identified institutional barriers and other challenges that hinder adaptation to climate change. Demographic, socio-economic, technological, cultural, and psychological factors influence farmers' adaptation choices (Dang et al., 2019). In response, researchers have determined that strengthening institutional capacity, including both formal and informal institutions, is more effective than solely focusing on agricultural technology (Aryal et al., 2020; Islam & Nursey-Bray, 2017), as institutional and policy challenges, including limited capacity for adaptation planning and implementation, further impede farmers' efforts to respond effectively to climate change (Alie et al., 2024). Farmers often struggle to access critical institutional support such as markets, climate information, agricultural inputs, and credit facilities (Mu et al., 2020). Failure to adequately understand the effectiveness of such measures and the absence of a supportive and integrative agricultural adaptation program are two additional barriers (Vignola et al., 2015). Cultural and psychological factors, such as traditional attitudes resistant to change, also hinder adaptation efforts (Alie et al., 2024).

Despite growing scholarly interests in climate change and agriculture, several critical gaps remain. First, while studies emphasize farmer awareness of climate change, they often fail to provide a holistic perspective on how farmers perceive the significance of climate-related stressors relative to other pressing challenges, such as labor shortage, labor cost, market dynamics, sales, and land tenure issues. This study addresses this gap by examining the relative significance of climate change among the myriad challenges faced by farmers. Second, most studies on climate impacts in China have generalized the direct effects on crop yield losses and food security, particularly for staple crops, including rice (Saud et al., 2022; Xiong et al., 2009), wheat and maize (Song et al., 2022; Zhang et al., 2022), and potatoes (Huang et al., 2022). In contrast, our study broadens the scope to include indirect impacts on agroecosystems, farm infrastructure, and farmers' health, emphasizing the multifaceted nature of climate stressors beyond immediate yield losses.

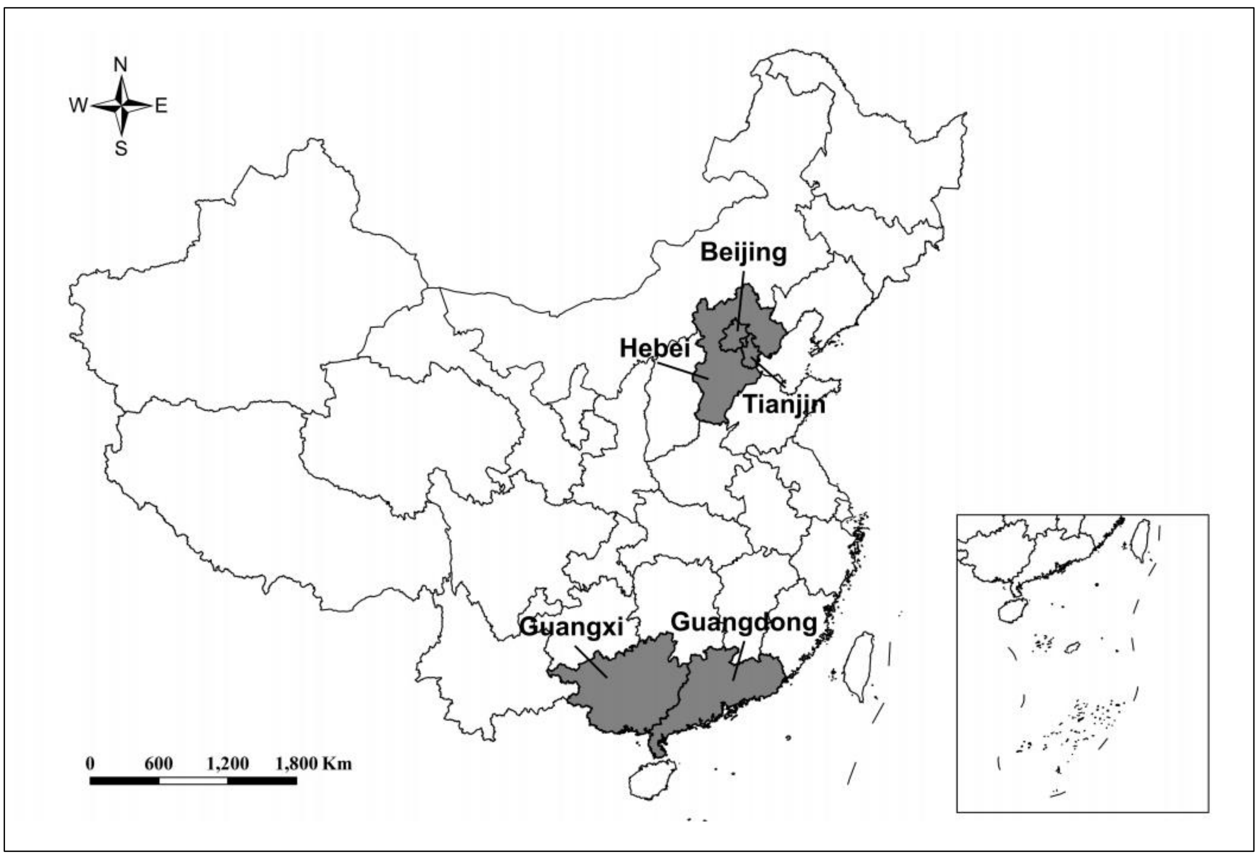
Furthermore, China's governmental climate strategies are centered on agricultural infrastructure, technology, and insurance (Wang et al., 2014), but these policies are often one-size-fits-all, disregarding the nuanced realities and diverse needs of smallholders. In addition, adaptation studies (H. Chen et al., 2014; Jin et al., 2020; C. Li et al., 2013) rarely distinguish between conventional farmers and ecological farmers. This is understandable, because the very small number of ecological farmers in China makes them less prominent in large-scale regional surveys. Systemic review of Chinese farmers' adaptation practices show that increased chemical inputs are among the most adopted practices (J. Chen et al., 2022), which leaves the adaptation experiences of ecological farmers largely underexplored. This disconnect not only limits the effectiveness of adaptation measures but also risks marginalizing small-scale ecological farmers by failing to incorporate their local knowledge, context-specific practices, and adaptive strategies into policy frameworks. By shifting the focus toward this particular farmer group—small-scale ecological farmers—the study provides nuanced empirical evidence of how they navigate the complex interplay of ecological, economic, and social factors in climate change adaptation, offering valuable insights into the broader dynamics of agrarian changes.

Research Methods

To effectively illustrate the diverse impacts of climate change on ecological farmers and their adaptation practices, we selected Guangxi Zhuang Autonomous Region and Guangdong Province to represent southern China, and the Beijing-Tianjin-Hebei region for northern China (Figure 1). Both regions experienced significant climate variability in recent years: heavy precipitation in North China (2021), extended drought in South China (2021 and 2022), and unprecedented rainfall in the Pearl River Delta (May–June 2022). These events ranked among China's top ten extreme weather and climate events for 2021 and 2022 (China Meteorological Administration, 2021, 2023). The proximity of these regions to major economic hubs—the Beijing-Tianjin-Hebei Region and the Pearl River Delta—further supports their selection. Urban consumers' purchasing power, diverse diets, heightened food safety awareness, and environmental concerns drive the prosperity of the ecological agricultural sector (Scott et al., 2018; Shi et al., 2011).

In early May 2022, a recruitment letter was disseminated through local environmental organizations, inviting ecological farmers in the two regions to participate. The research targeted farmers practicing ecological or organic production methods for crop planting or livestock raising, without using synthetic chemicals such as fertilizers, pesticides, growth hormones, and herbicides. In terms of farm size, we considered the Food and Agriculture Organization of the United Nations' (FAO) definition of small-scale or smallholders as those managing from less than one to ten hectares (2013), as

Figure 1. Locations of the Two Study Sites in China (Shaded Areas)



well as the benchmarks established in China's Third Agriculture Census. Accordingly, we defined small-scale farms in this study as those with a cultivated acreage not exceeding 200 mu (~13.3 hectares), with exceptions for agroforestry or orchards. Despite their relatively small size, most of these farms are not subsistence-based but are market-oriented. In addition, we solicited recommendations from non-government organizations operating in the study areas to extend outreach, resulting in a sample of 28 farms. As the objective of the study is to gain in-depth insights rather than to achieve statistical generalizability, the sample is not intended to be fully representative of all small-scale ecological farmers in China.

Beginning in early May 2022, the lead researcher conducted in-depth interviews (online and in person), farm visits, structured surveys, and follow-up conversations via WeChat, the most popular communication and social media app in China, or phone calls to collect data. Ethics approval for this study was obtained from the Office of Research Ethics at the University of Waterloo in Canada (No. 41206). Consent was obtained through WeChat messages. Semi-structured interviews collected both biophysical and socioeconomic data. As much as domestic COVID-19 prevention and control policies permitted, we visited most respondent farms. After interviews and field trips, we distributed questionnaires to the 28 respondents, addressing key issues identified during the interviews and site visits, as well as new issues that emerged during the aggregation of interview data. Supplementary questionnaires explored emerging issues in greater depth, and follow-up communications helped enrich the findings. A total of 28 ecological farms were studied: Beijing (5), Tianjin (1), Hebei (5), Guangxi (8), and Guangdong (9), with 20 visited on-site by June 2023. While achieving absolute saturation is ideal, in qualitative research saturation may not always be fully attainable in studies involving hard-to-reach or specialized populations, such as this newly emerged group of Chinese small-scale ecological farmers. As we strived to achieve in this study, focusing rather on the depth and richness of the data can provide meaningful insights, even in the absence of complete saturation.

The primary scale of analysis in this study is the farm-level. Detailed notes were taken during all interviews. For online interviews conducted via Tencent Meeting, recordings were used to verify the notes. Interviews were then transcribed in Chinese. Relevant information and raw data were then extracted from the transcripts, categorized, and analyzed using an inductive approach to explore awareness and perception of climate change, its impacts on production and livelihoods, and current adaptation measures. As conventional smallholders were not included in the study, comparison between small-scale ecological and conventional farmers was conducted by using the narratives from participants and information drawn from existing literature. The following sections review the key findings.

Profiles and Heterogeneity of the Ecological Farmers and Farms

Compared to the general farmer population profiled in China's Third National Agricultural Census (National Bureau of Statistics, 2017), the ecological farmers in this study are younger and better educated (Table 1). About 53.6% (15 of 28) of respondents held an associate degree or higher, in stark contrast to the national average of 1.2%. This aligns with findings by Burton (2014) that more

Table 1. Demographics of Respondents in Comparison with Data from China's Third National Agricultural Census (Released in 2017)

	In this Study	Third National Census
Gender		
Male	71.4% (20/28)	52.5%
Female	28.6% (8/28)	47.5%
Age		
<35	21.4% (6/28)	19.2%
36–54	71.4% (20/28)	47.3%
55>	7.1% (2/28)	33.6%
Education		
No schooling	0	6.4%
Primary school	3.6% (1/28)	37.0%
Junior middle school	25.0% (7/28)	48.4%
Senior middle school	17.9% (5/28)	7.1%
Associate degree and above	46.4% (13/28)	1.2%

educated farmers tend to have a better understanding of ecological systems and are more likely to adopt sustainable practices. Notably, five respondents majored in agriculture or related fields. Ages ranged from 26 to 56, with an average of 42, significantly younger than the 58.6-year average for farmers recorded in a 2013 Jiangsu Province survey (Zou, 2013). Eight respondents were female, half of whom worked collaboratively with their husbands on the farm.

Although all farms are ecological, there is considerable variation in farm size, land tenure, terrain features, crops and livestock variety, and their business scope. Farm size ranges 0.4 mu (~0.027 hectare)–300 mu (20 hectare). Nine farms are on plains, and others are in terrains that include hills, mountains, basins and coastal land. Of the 28 farmers, 18 operate entirely open-air fields, with greenhouses or cold frames areas typically less than one-third of the total farm space. Sixteen farms can be simply classified as "family farms," relying primarily on family labor. Eight farms have diversified into activities such as hosting nature education programs, bed-and-breakfast services, and fruit-picking.

Awareness and Perception of Climate Change Impacts

Interviews and surveys show that small-scale ecological farmers generally perceived climate change as having significant impacts (Table 2). Over two-thirds of survey respondents rated the impact over the last five years as "major" or "significant," with none reporting "minor" or "no impact." These ratings, while subjective, reflect a high level of awareness which could contribute to farmers' proactive approach to adaptation (Jin et al., 2020).

In addition to climate risks, farmers faced various socio-economic challenges. To assess the relative significance of these issues, farmers were asked to rank their top three concerns from a list we compiled through interviews and site visits (Table 3). Climate change and extreme weather topped the list of concerns for 15 farmers, with an additional eight ranking it among their top three. Rising labor costs followed, noted by 16 farmers, while market sales were a priority for 15. Other concerns included worker availability, consumer attitudes towards eco-food, land tenure stability and rising land rents. Notably, six farmers held household contracting rights[1] to their land, which may explain

Table 2. Farmer Perceptions of the Impacts of Climate Change in the Last Five Years

Different Levels of Perceived Impact	Number of Farmers Selected	%
No Impact	0	0%
Minor Impact	0	0%
Moderate Impact	9	32%
Major Impact	14	50%
Significant Impact	5	18%
Total	28	100%

Table 3. Top Three Concerns of Climate Change Relative to Social-Economic Stressors

Concerns	1st Choice	2nd Choice	3rd Choice	Total Mentions
Climate Change/Extreme Weather	15	5	3	23
Rising Labor cost	3	5	8	16
Market Sales	5	5	5	15
Availability of Workers	3	4	4	11
Consumer Awareness of Eco-food	1	5	3	9
Land Tenure Stability	1	3	1	5
Rising Rents for Land	0	1	4	5

[1] In China, all agricultural land is owned by the state or rural collectives, while farmers have "contracting rights" which allow them to access land through contracts with the rural collective. If a farmer wishes to cultivate land for which they do not hold a contract, they must lease it from other farmers or the rural collectives.

the low ranking of "land tenure stability" and "rising rents." Furthermore, these concerns were often interconnected. For instance, we discovered that extreme summer heat made it difficult to find labor in aging rural communities, as aged people avoid outdoor work to prevent heatstroke. A farmer in Guangdong stated:

> I am the only '90s-born person farming in the nearby villages. From mid-June to mid-August, even if I offered 120 yuan a day, I couldn't find extra help in nearby villages. They said it was too hot. Even a few people said they were willing to work, but their grown-up children wouldn't allow them to work in such hot weather.

When asked about the potential impact of climate change over the next five years, 15 respondents anticipated greater damage, while 13 expressed uncertainties. During the interviews, some farmers perceived extreme or abnormal weather events as isolated incidents rather than indicators of a broader trend, which may partly explain their uncertainty in predicting future impacts. A female farmer in Guangdong Province explained:

> We didn't think of it as climate change. Locals just consider it a natural disaster. For example, this year, it rained continuously for a month, or even two months. I don't know whether these events are isolated or part of a larger change. We just feel helpless and out of options.

Climate Change Impacts

The most significant and widespread climate change impact perceived over the past five years was yield loss, followed by disrupted farming schedules, damage to farm facilities, and impacts on farmers' health (Table 4). These impacts are consistent with findings from other studies globally. In-depth interviews provide detailed insights into specific instances of production loss, as well as broader effects on farmers and the agroecosystem.

Of the 28 farmers, 26 reported losses in crop or livestock production with 12 reporting over 50% losses of a single crop; three even suffered total crop failures. Extreme temperatures during critical growth or maturity stages of crops were a major cause. For instance, one farmer encountered continuous rainfall during the ripening period of rice, which prevented harvesting and caused the mature rice to germinate on the ears. Some extreme weather events, while not reducing yield, impaired the commercial value of farm produce. One farmer described how apples bruised by hail became unsellable.

The respondents also revealed that changes in temperatures and precipitation, and the increasing frequency and intensity of extreme weather events significantly disrupted farm ecosystems. Several farmers cited that unprecedentedly prolonged rainfall has harmed pollinators and triggered pest and pathogen outbreaks. A month-long rain in Guangxi in May 2022 almost halved the bee population of a local farmer who was also a beekeeper. Another farmer in Beijing observed that drought-inflicted dry soil led to rampant pests such as aphids and red spiders. Several farmers mentioned sea water intrusions in the Pearl River Delta region due to prolonged droughts in 2022. The elevated salinity level hindered crop growth and required extra irrigation to reduce soil salinity. Farmers also reported proliferations of invasive species in recent years. In Conghua, Guangdong Province, increasing number

Table 4. Climate Change Impacts Experienced by Farmers Over the Last Five Years

Impacts on Farming Operations	Number of Farmers Reporting
Crop/Livestock Loss	26
Disrupted Farming Schedules	16
Single Crop Loss > 50%	12
Flooding of the Farm	7
Damage to Farm Facilities	6
Pollination Issues	5
Health Issues	5
Total Crop Failure of a Single Item	3
Disrupted Transportation	2
Soil Salinization	2
Damage to Farm Roads	2
Water Access Issues	1
Power Outages on the Farm	0

of needle bees (fruit flies) attacked local fruits such as citrus and guavas and vegetables such as pumpkins and loofah unless the young fruits and vegetables are protected with plastic or paper bags.

A less commonly discussed dimension of climate change is its impact on farmer health, particularly pertinent to ecological farmers as they rely more heavily on manual labor (e.g., for weeding, pest control, harvesting). While outdoor workers in the agricultural sector are among the most vulnerable to heightened risks of heat stress under global warming (Kjellstrom et al., 2019), there is little research connecting climate change and farm labor productivity (De Lima et al., 2021). We found that many farmers were forced to shift working hours to avoid excessive heat on hot summer days. Five respondents experienced heatstroke, with older workers—commonly employed by ecological farms—particularly vulnerable due to both the intense physical demands of the work and the heightened risk of heat-related illness. A farm operating manager reported a labor shortage in July 2022:

> Our farm has hired aunties who are between 60 and 70 years old. Due to fear of heatstroke, many of them finished work and left for home by 3 P.M. Several others took breaks during this hot month.

Another pressing concern found in our fieldwork is the increasing intersection between farm ecosystem change and farmer health, both exacerbated by climate change. In recent years, farmers in Guangzhou have noticed the disturbing presence of invasive red fire ants on their farms, damaging crops and posing health risks through painful stings, potentially causing severe allergic reactions. Scholars attribute the proliferation of this intrusive species to climate change and global trade, predicting that suitable habitats for these ants will expand into higher latitudes under future climatic conditions (D. Li et al., 2023). This threat has made labor recruitment more difficult, with some farmers resorting to machinery as a substitute.

Adaptation Measures

Our study categorizes farmers' approaches to mitigating the impacts of climate change into two main dimensions: farm-level ecosystem-based adaptations and socio-economic activities. The first dimension focuses on management practices that leverage biodiversity, ecosystem services, and ecological processes to bolster the resilience of crops and livestock to climate variability (Vignola et al., 2015). The second broadens the scope of adaptation to encompass a wide range of socio-economic interventions, including infrastructure enhancement, insurance for risk sharing, and strategies of income diversification and continued learning ways to strengthen adaptive capacity.

Farm-level Ecosystem-based Adaptation Measures

Nearly all farmers emphasized that adding organic matter to the soil is the primary and most important step in improving soil fertility and structure. Composting was the most commonly adopted measure, as more than two-thirds of the farmers made natural organic fertilizers through composting. While some farmers purchased commercial microorganisms to improve soil, one farmer in Guangxi adopted a more locally embedded economical approach. He collected soil containing beneficial microorganisms in nearby bamboo forests and made his own liquid bacterial culture. He then sprayed it on soil to balance the bacterial flora and prevent the growth of pathogens. The farmer explained:

> If I buy commercial products, I don't know what ingredients they use or how they are produced. But I know I collect microorganisms and cultivate them in a very ecological, pollution-free environment. So, I think the microorganisms I produce are safer, and using local microorganisms in local farms makes them more effective.

Another major strategy to improving soil quality is integrating livestock-crop production systems. Fifteen growers also raised various animals, including cattle, pigs, chickens, ducks, fish, and even earthworms, and used their manure as natural fertilizer to boost soil fertility. Diversified cropping increases the temporal and spatial diversity of agricultural systems through practices such as intercropping, crop rotation, and the use of cover crops, important to boost the resilience of the agroecosystem against climate change (Kremen & Miles, 2012; Lin, 2011).

All respondents practiced polyculture, with six cultivating over 50 kinds of grain, vegetables and fruits all year round. In addition, a number of farmers grew legume plants as companion crops or green manure, while some left strips of natural vegetation in the fields. The benefits they described include lowering ground temperature, retaining soil moisture, reducing soil erosion, and providing habitats for pollinators and natural pest predators. A mandarin orange grower in Guangxi reported that a few years after applying a range of ecological practices without chemical pesticides, as the agroecosystem in her farm became more resilient the damage caused by the outbreak of fruit flies in 2022 was negligible. A farmer who grows clementines kept grass in the fields as a living mulch and constantly added organic matter to improve the soil quality. During the driest season, in 2022, he was envied by a neighboring conventional farmer who had to water the farm twice as often. In addition, a rice farmer in terraced fields noted that wild grass growing along the ridge sides helps stabilize the terraces, preventing collapses during heavy rainstorms.

Some farmers carefully chose their site by considering weather conditions and the surrounding environment. A farmer in Guangdong Province spent eight months evaluating potential sites. After spotting fireflies at a prospective site, an indicator of clean water and unpolluted soil, he reviewed 15 years of local meteorological data and spent two months living in the village to observe the area during typhoons before making the final decision to lease the land.

Farmers actively select types and varieties of crops and livestock breeds that are well-suited to their local landscape and climate conditions, thereby optimizing productivity and sustainability. On a farm in Guangzhou, fields prone to flooding were converted to rice paddies and fishponds, making full use of the natural water flow and retaining the run-off nutrients. Landraces, also known as "old seeds" or "family heirloom," are selected generation after generation by farmers due to their proven suitability for the local environment. A farmer in Guangxi found that local rice varieties have better drought resistance than mainstream commercial seeds in the market. A farmer growing shaddock in Guangxi said that the white Shatian shaddock his family has been growing since 1987 has always maintained a stable yield even without intensive management.

In summary, small-scale ecological farmers integrate local knowledge, sustainable practices, and innovative transformations to address climate change. By focusing on soil health, biodiversity, and tailored adaptations to environmental conditions, they showcase the holistic approach to resilience advocated by agroecology, presenting a stark contrast to the practices typically employed by conventional farmers. By leveraging locally available resources, integrating livestock-crop systems, and selecting traditional landraces, these farmers optimize productivity while maintaining sustainability. Their transformations of landscapes, such as converting flood-prone fields into productive systems, highlight the potential of ecological farming to address climate and economic challenges.

Adaptation Measures at Social-economic Levels

Adaptation to climate change has limits, especially when confronting extreme weather events (Aryal et al., 2020). Ecological farmers in South China indicated the need for new investments in crop cultivation facilities to counter the rare extreme cold of winter and extended droughts in recent years. Conversely, in Hebei province, where annual precipitation is only half of that in the Guangdong and Guangxi Region, farmers are adapting to abnormally heavy and concentrated precipitation in the summer. Although it was challenging to quantify the overall cost involved, several cases in our study revealed a wide range of expenses, from less than US$300 to more than US$41,000. Larger farms, with better access to bank loans and subsidies, demonstrated a greater financial capacity to invest in climate-resilient infrastructure such as greenhouses, cold storage, and machinery. Notably, two farms that constructed greenhouses or cold storage received government support covering up to 40% of the costs. Small-scale investments such as repairing roads damaged by heavy rains, building rainwater harvesting pools, and excavating wider trenches for better drainage were typically self-funded. A farmer who owns chicken houses uphill had to repair roads after heavy rains several times in the summer of 2022:

> Because only I use the mountain roads to feed the chickens daily, I had to pay out of my pocket to rent an excavator and hire people to repair the road; otherwise when the rain stops and the muddy road dried, it would become very dangerous to drive a three-wheeler along the path.

Such constant investments in farm infrastructure to adapt to climate change offer valuable insights into the operational resilience of these ecological farms. Of the 28 farmers who had an average of seven years in the business (duration of operation ranging 3–19 years), only nine have recouped their initial investments and are currently operating at a profit. Eight are self-sustaining, with annual revenues covering all expenses but without generating profit. The remaining 11 still need to rely on personal financial contributions to make ends meet.

As Magesa et al. (2023) have discussed, future extreme climate scenarios necessitate more transformative measures like improved infrastructure, crop insurance, and livelihood diversification. We found that ecological farmers' diversification strategies in livelihood and business serve as an effective adaptation approach to reducing climate change risks, although climate change might not be the sole motivator for these changes. For example, a farmer in Guangxi is currently working temporarily to renovate downtown flats to cover operational costs of his farm and his family's living expenses. Besides off-farm jobs, agritourism and other on-farm services such as fruit-picking, homestay, and nature education courses were offered on eight farms to bolster their economic viability. A farm in Guangdong province organized firefly-themed nature education activities every July and August, that generated sufficient revenue to cover the operational costs of the farm for an entire year.

Although insurance is often proposed as an effective approach to cope with the impacts of climate change (Falco et al., 2014), only four of the 28 farmers had purchased agricultural insurance and only one of them received compensation after purchasing the weather index insurance. We found that ecological farmers are less willing to purchase government-subsidized insurance compared to conventional farmers, due primarily to uncertainty about coverage eligibility for vegetables, difficulties in assessing the size of certain crops due to diversified cropping and intercropping practices, and concerns that the time and effort required for the application and claims process may outweigh the expected compensation, which is calculated based on the costs and prices of conventional farm produce. Sometimes small farm size even made them ineligible for insurance. A farmer wanted to buy insurance for the pigs she raised from a local insurance company but found that such insurance is only available for farms with over 30 pigs: "Although I only raised a few, that number could be all that a small farmer has. Insurance should be accessible for farmers equally."

The two sets of adaptive measures highlighted above are not exhaustive; rather, they represent crucial insights derived from our findings. To gauge the relevance of these measures, in the supplementary questionnaire farmers were asked to select the top five adaptive measures they considered most effective (Table 5). Responses indicated a strong preference for ecosystem-based measures, such as diversified cropping and soil improvement. Their preference for soil improvement aligns with the findings of Lal et al. (2011), which emphasized the importance of increasing soil organic matter and improving aggregate structure to bolster small farm resilience against climate change. While ecosystem-based measures dominate the list, reflecting farmer confidence in ecological practices, several measures regarding infrastructure enhancement were also recognized as viable strategies by a significant number of farmers, suggesting the pragmatic approach of ecological farmers in adopting diverse measures to mitigate risks.

Discussion

This section examines ecological farmers' approaches to climate change and the lessons they offer for broader agricultural adaptation. Central topics include ecosystem-based practices, the use of local knowledge, and the challenges of limited institutional support. We also discuss the complexities of balancing farm size with adaptation strategies, and identify insights that can inform more sustainable and inclusive policies, particularly for smallholders. The findings on climate change impacts and adaptation strategies are contextualized through comparative analysis with existing literature.

Table 5. Measures Considered Effective by Farmers to Mitigate Climate Risks and Impacts (Multiple Choice)

Measures	Category	Number of Farmers Selected
Diversified Cropping	Ecosystem-based	20
Soil Improvement	Ecosystem-based	19
Farmland Planning	Ecosystem-based	14
Strengthen the Drainage System	Socio-economic	11
Water Harvest/Irrigation Systems	Socio-economic	10
Integration of Planting and Breeding	Ecosystem-based	9
Cover Crops	Ecosystem-based	8
Intercropping/Rotation	Ecosystem-based	8
Greenhouse Enhancement	Socio-economic	7
Choose Landraces	Ecosystem-based	7
Choose Stress Resistant Varieties	Ecosystem-based	6
Biological Pest Control	Ecosystem-based	5
Nutrient Management	Ecosystem-based	4
Attending Training for Knowledge and Skills	Socio-economic	4

Adaptation Capability in Comparison with Conventional Farmers

A primary goal of the study is to understand how ecological farmers cope with climate change compared to conventional farmers, with the aim of identifying innovative strategies to inform broader agricultural adaptation. This section presents the key differences between the two groups. Jin et al. (2020) found that conventional farmers primarily adopt three critical adaptation strategies: switching to drought-resistant crop varieties, adjusting pesticide use, and modifying fertilizer application practices. J. Chen et al. (2022) showed that major adaptive strategies employed by conventional farmers in China are crop variety adjustment, changing farming schedules, increasing chemical inputs, and enhancing irrigation.

While selecting crop varieties, adjusting farming schedules, and enhancing irrigation are common practices for both conventional and ecological farmers, they differ in agricultural inputs. Conventional farmers resort to chemical inputs as a coping strategy, which may bring immediate effects but can lead to pesticide resistance and soil degradation in the long term (Afsar & Sadavarte, 2024). Furthermore, a study by Quan et al. (2019) of small conventional wheat farmers' adaptation strategies in Henan identified frequent misapplication and overuse of chemical inputs, resulting in significant yield losses. In contrast, practices employed by ecological farmers such as adding organic matter to the soil by composting, relying on labor inputs, and sticky traps and organic sprays for pest control might not prevent immediate yield losses but would boost the overall resilience of crops and enhance the farm ecosystem in the long run (Ekström & Ekbom, 2011). This distinction underscores the potential for ecological farming to inform broader agricultural adaptation strategies, promoting more sustainable and knowledge-intensive solutions to climate challenges.

Another key difference lies in how knowledge and technological support are obtained. Ecological farming is a knowledge-intensive practice that emphasizes processes over inputs (Tittonell, 2013). While conventional smallholders typically receive support from local extension (H. Chen et al., 2014; Sattar et al., 2023), only one ecological farmer in our study reported having such support. Two-thirds have relied on self-study, and slightly less than half have attended training classes. Farmers tend to place greater trust in their neighbors and local model farmers than in agricultural extension staff. This lack of supportive and credible institutional support highlights the need for more inclusive policies and programs that integrate ecological farming practices into institutional frameworks.

In addition, while taking extra off-farm jobs may be a common livelihood adaptation strategy for both conventional and ecological farmers, ecological farms offer unique value as serene pastoral retreats for urban dwellers and ideal venues for nature-based education. Several farms have successfully diversified into agritourism and educational programs, generating extra revenue beyond from farm produce. Such initiatives demonstrate that diversified and creative usage of ecological spaces would enhance the economic viability of small ecological farms.

Promising Practices Yet Persistent Challenges

This study provides evidence on the efficacy of ecological farming in mitigating the impacts of climate change through enhanced pest resistance, improved water conservation, and increased yield. Despite some successes, significant gaps remain. We found that the complex dynamics of the agroecosystem induced by climate change are beyond the knowledge and control of individual farmers. Many farmers who tended their farms with great care, and in some cases hold college degrees in agriculture, have observed but struggled to fully understand the dynamic interactions among pests, natural enemies, and plants under varying climate shocks. A clementine farmer, perplexed by climate patterns in the past three years, noted that the prevailing pests on the farm changed each year. Other issues such as invasive species also prove difficult for individual farmers to handle alone. These observations call for more farm-level monitoring and participatory research to investigate the micro-situations of agroecosystem dynamics under various climate scenarios.

Farm Size and Tailored Policies to Boost Adaptation Capacity

While it sounds like an obvious finding, our study affirms the positive correlation between farm size and the cost of climate adaptation measures. Smaller farms mainly use low-cost agronomic practices such as making compost and enzymes for soil enhancement, and better conserving of water. Relatively larger farms spanning several hectares seem to have more financial resources to enhance adaptive capacity, enabling investments in infrastructure such as greenhouses and cold storage facilities. Additionally, it is more economical for large farms to purchase crop insurance, since the time and effort to apply and claim compensation are less cost-effective for smaller farms. With global warming and more frequent extreme weather events, current policies could place the smallest farms with limited access to financial subsidies and insurance coverage in a particularly vulnerable position.

However, not all economic realities are working in bigger farms' favor. Government subsidies oriented to larger farms might incentivize bigger investments, but ecological farming's inherently labor-intensive nature and the associated high costs can pose substantial challenges to large farms. According to respondents, labor costs constitute a big chunk of their annual operational expenses. With an aging rural population, bigger ecological farms find it even more difficult and costly to hire labor. With up-scaled production capacity, bigger farms will face more pressure to market and sell the produce compared to smaller ones. In contrast, smaller farms that primarily rely on family labor and direct sales to consumers might enjoy greater flexibility in adjusting their operations. These dynamics align with Stringer et al.'s observation that different types of farms following different pathways require tailored support for their adaptation and development (2019).

As China's agricultural sector is dominated by over 200 million smallholders, the ecological adaptation strategies developed by small-scale ecological farmers, along with their practical experiences, hold immense value for advancing the sustainability transition of Chinese agriculture. Small-scale ecological farmers operate with limited resources and face significant climate stressors, making their strategies highly relevant for other smallholders who need cost-effective and sustainable solutions. The smallholder nature of China's agricultural sector aligns closely with the principles of agroecology, which advocates small-scale, resource-efficient, and ecologically sound practices. Agroecology thus offers a viable pathway toward long-term sustainable development, as it leverages the strengths of smallholder farming systems demonstrated in our study, such as localized knowledge, diversified production, and close integration with natural ecosystems.

Conclusion

With a sample consisting of 28 small ecological farms in Beijing-Tianjin-Hebei area and Guangxi and Guangdong area, we investigated their perceptions of climate change and the impacts they have experienced. This study contributes to the existing literature by providing a holistic perspective on how climate stressors are perceived by farmers relative to other pressing challenges. Despite diversity among the farms in size and landscape, two-thirds of the farmers believed that the impacts brought by climate change were substantial. The reported impacts such as yield loss, disrupted schedules, pest outbreaks, and health risks, reflect patterns seen across sub-Saharan Africa and South Asia, where erratic weather and pests threaten smallholder productivity (Aryal et al., 2020; Morton, 2007). These findings likely explain why the majority ranked climate change/extreme weather as their top concern compared to other market-, labor- and land tenure–related factors. Nevertheless, some farmers still perceived the abnormal weather events in recent years as isolated incidents rather than indicators of a long-term trend. Such a perception might explain the uncertainty among 12 of the respondents about whether more severe impacts would take place in the coming years. This underestimation of future climate challenges demonstrates the need to further raise farmer awareness of climate change in the long run.

This study broadens the scope of existing research on climate change impacts on Chinese farmers, which often focuses on the direct impacts, by incorporating an analysis of indirect effects across multiple dimensions, including agroecosystems, farm infrastructure, and health. Beyond direct impacts on yield and quality, disturbed ecosystems manifested pollination failure, pest and pathogen outbreaks, and invasive species and sea water intrusion which also exacerbate farmer hardship. Moreover, extreme weather such as heat waves affects farmers' health and brings more health risks to aged workers in particular, a topic underexplored in China despite global recognition of heat stress risks in agriculture (Kjellstrom et al., 2019). These findings highlight the pressing need to mitigate the multifaceted impacts of climate change in China, especially with the vulnerabilities of its rapidly aging agricultural workforce.

This study contributes to the field of climate change research by offering a nuanced analysis of the lived experiences and adaptive strategies of a specific subgroup of farmers—small-scale ecological farmers. It shows the potential of ecological adaptation approaches to cope with climate change without applying agrochemicals, thus also contributing to a more sustainable agricultural system. Adaptation strategies like soil improvement, diversified cropping, livestock integration, and the use of landraces mirror agroecological approaches promoted internationally (Altieri et al., 2015; Kremen & Miles, 2012). Moreover, use of locally sourced microorganisms and site selection based on ecological indicators (e.g., the presence of fireflies) reflects a deeper application of local knowledge than is typically documented in adaptation literature, supporting insights from Bhatta et al. (2017) on the value of local knowledge in climate adaptation. As we found that farmers trust their neighbors and model farmers much more than extension service staff (Fan et al., 2022), there is an opportunity to leverage model farms as knowledge hubs, through a farmer-to-farmer extension model, for spreading ecological farming knowledge and sustainable adaptive practices to a broader but local audience. This could also help address the gap in existing agricultural extension systems, which often lack sufficient information about sustainable agricultural practices.

The necessity to adapt to extreme weather in recent years has also compelled many farmers to construct new infrastructure or improve existing facilities such as greenhouses, rainwater collection, irrigation, and drainage systems. In addition to pursuing part-time jobs as a livelihood diversification strategy, ecological farmers can enhance their economic viability by utilizing the ecological space of their farms in creative ways. These socio-economic responses, ranging from infrastructure upgrades to agritourism and off-farm employment, align with broader resilience strategies (Bryan et al., 2009; Mertz et al., 2009), though many farmers face high costs and delayed returns. Moreover, challenges with insurance uptake are typical of global findings, as smallholders are deterred by eligibility gaps and complex claims processes (Surminski et al., 2016).

With small ecological farms also facing more institutional barriers to obtain government subsidies, there is need for government policies tailored to different farm sizes and effectively boosting their adaptive capacity. This is consistent with Hou and Wang's (2025) call for establishing a multi-level agricultural insurance system that provides basic and additional insurance and extends coverage to more cash crops.

The study presents a nuanced and multifaceted picture of the research objective: to deepen our understanding of whether and how ecological farming can be a sustainable and economically viable pathway for smallholders in China and beyond. On the environmental front, the evidence strongly supports the sustainability of small-scale ecological farms. They tend to use fewer synthetic inputs, foster biodiversity, improve soil health, and reduce pollution, demonstrating clear ecological benefits that align with global sustainability goals. On the economic front, despite innovative uses of farm space such as agritourism and nature-based education proven effective in generating additional income, the economic viability of these farms is often precarious. This multifaceted picture underscores that ecological farming holds promise as an environmentally sustainable model, but its broader and successful adoption among smallholders is contingent upon overcoming substantial economic, social and institutional barriers. For other countries or regions where smallholders dominate agricultural production, this suggests that transitioning to ecological farming must be coupled with targeted interventions, such as capacity building, institutional support, market development, and inclusive policies, to create enabling conditions for success. The experiments of small-scale ecological farms in China also suggests that policies should recognize and support bottom-up, farmer-driven innovations in ecological practices, while avoiding prescriptive top-down directives.

Despite these many observations, the response and interaction mechanisms among plants, animals, and microorganisms on the farm when exposed to climate stressors remain unclear. We hope this study will open the door to more quantitative and participatory research to identify, develop and evaluate cost-effective and accessible ecological practices dealing with climate change. This will not only assist ecological farmers but could also pave the way for scaling up ecological practices among the much broader population of smallholders across China, enhancing their adaptive capacity and promoting sustainable agriculture. Due to the small sample in this study, larger-scale studies that cover more diverse samples of small-scale ecological farmers are necessary. While our findings are not fully generalizable to all smallholders across China, they nonetheless offer important insights that can inform broader discussions on sustainable adaptation. Further research is necessary to explore the unique factors, such as environmental values, educational backgrounds, and local socioeconomic conditions, that shape the adaptation decision-making processes of ecological farms. By drawing on the experiences of small-scale ecological farmers, China's agricultural sector could demonstrate how smallholder agriculture can lead a sustainable response to climate change and other global challenges.

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