Dean&Francis

ISSN 2959-6157

Mechanisms and Case Studies of the Impact of Climate Change on Agricultural Development

Muye Chen [1,*]

[1] Beijing No.2 Middle School, Beijing, China
* Corresponding Author: chenxavier228@gmail.com

Abstract:

Global climate change is becoming increasingly severe, with rising temperatures, abnormal precipitation, and frequent extreme weather events posing a continuing threat to agricultural production and ecosystem security. Agriculture is the most climate-sensitive sector of the economy, and the extent of its impact is directly related to food security and social sustainability. This paper systematically reviews the four main mechanisms through which climate change affects agricultural development, including the impact of rising temperatures on crop growth cycles and yields, the effect of changes in precipitation patterns on irrigation security and water supply for farmland, the increase in agricultural disaster risks due to extreme weather events, and the indirect impact of climate warming on the stability of agricultural ecosystems. On this basis, the Mekong Delta in Vietnam and the rice-growing regions of China were selected as typical case studies to analyze the regional differences and main characteristics of the mechanisms of climate change impacts, and to explore local response measures and adaptive control strategies. Research has found that there are significant differences in the mechanisms of climate change impacts across different regions. Rising temperatures and extreme events pose a significant threat to rice production, while water scarcity and sea level rise have a particularly pronounced impact on delta regions.

Keywords: Climate change; Agricultural impacts; Regional differences; Adaptation strategies.

1. Introduction

Global climate change is becoming increasingly significant, with rising temperatures, abnormal precipitation, and frequent extreme weather events becoming its main characteristics. These changes have had a profound impact on agricultural production, threatening crop yields and food security, disrupting the balance of agricultural ecosystems, increasing the risk of agricultural disasters, and ultimately affecting the sustainable development of society. Therefore, studying the mechanisms by which climate change affects agricultural development and exploring adaptive control measures are of great practical significance for ensuring food security and achieving sustainable agricultural development. As summarized in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, climate change has already affected food security due to warming, changing precipitation patterns, and greater frequency of extreme events [1].

In recent years, scholars at home and abroad have conducted extensive research on the impact of climate change on agricultural production. Existing research findings have mainly focused on the effects of rising temperatures on crop yields and growth and development, the role of precipitation changes in water resources and farmland irrigation security, the increase in agricultural disaster risks caused by extreme weather events, and the indirect impact of global warming on the stability of agricultural ecosystems. These studies have revealed the multidimensional impacts of climate change through crop physiology, water security, and pest and disease occurrence patterns, enriching the theoretical framework of agricultural climate risk mechanisms. However, existing research has mostly focused on analyzing the mechanisms of impact, lacking systematic verification through typical regional case studies and providing few summaries of regional adaptation strategies, resulting in insufficient practical guidance.

Based on this, this paper systematically reviews the main mechanisms by which climate change affects agricultural development. Two typical regions, the Mekong Delta in Vietnam and the rice-growing region in China, are selected to verify the universality and regional characteristics of climate change mechanisms. Based on these cases, the paper proposes adaptation strategies tailored to local conditions, providing a reference for improving the regional agricultural climate adaptation theory and practice system.

2. Main Impact Mechanisms

2.1 Impacts of Temperature Rise on Crop Growth

Climate warming is one of the climate factors that cannot be ignored in agricultural production. Temperature affects the physiological processes and growth patterns of crops, thereby affecting crop yield and quality. The growing season of crops accelerates as temperatures rise. Crops will sprout, flower, and mature earlier. The grain filling period will also be shortened. This reduces photosynthetic products, leading to lower yields. For temperature-sensitive crops such as rice and wheat, high temperatures during the sprouting and flowering period can cause damage to the flowers and poor pollination, resulting in lower grain yield, seed setting rate, and grain weight.

Taking the rice-growing regions of southern China and Southeast Asia as an example, simulation studies show that for every 1°C increase in temperature, the average rice maturation period advances by approximately 5–7 days, and yields decline by 3.8%–4.5% [2]. For economic crops such as fruit trees and vegetables, high temperatures can also hurt their quality, such as reduced sugar content and shorter storage life, which can result in economic losses for agriculture. Currently, there are several methods for dealing with high temperature stress. First, changing the planting season can help avoid periods when high temperatures may cause damage. Second, select heat-tolerant and stress-resistant varieties. Third, optimize cultivation management measures. Fourth, improve the high-temperature meteorological disaster warning system. These adaptive measures can effectively increase the climate resilience of agricultural systems. According to Hatfield and Prueger, high temperatures accelerate crop phenological development, shorten the grain filling period, and ultimately reduce yield due to decreased photosynthetic duration and efficiency [3].

2.2 Effects of Altered Precipitation Patterns on Farmland Irrigation

Changes in precipitation patterns have become an important climatic factor affecting agricultural production, water resource supply, and the reliability of farmland irrigation. Changes in the spatiotemporal distribution of precipitation impact regional water resource systems, altering the water storage capacity of reservoirs and ponds as well as the base flow of rivers, thereby affecting the availability of irrigation water sources and posing serious threats to the stability and sustainability of agricultural production.

Abnormal climate conditions have led to an uneven spatial and temporal distribution of precipitation, disrupting the normal water supply pattern. During critical growing periods for dryland crops, water sources are either unavailable or the supply is uneven. This results in water stress, inhibiting crop growth and reducing photosynthetic rates. This is particularly true during critical periods such as the panicle initiation and heading stages of rice and the tasseling and silking stages of corn, when crops are highly sensitive to water demand. If the water supply is insufficient during these periods, issues such as flower degeneration, pollen deficiency, pollination disorders, impaired grain filling, and reduced grain set rates may easily occur. Ultimately, this can lead to shriveled grains and reduced yields.

To address the risks that changes in precipitation patterns may pose to water resource security in agricultural pro-

ISSN 2959-6157

duction, a series of measures must be implemented. First, it is essential to rationally optimize agricultural crop structures and irrigation quotas. Second, drought- and flood-resistant crop varieties should be developed. Additionally, water-saving irrigation technologies should be promoted, and water conservancy facilities should be upgraded. Concurrently, early warning systems for natural disasters such as droughts and floods should be established. Finally, achieve scientific decision-making in water resource regulation. These technologies and comprehensive measures can collectively enhance agricultural irrigation water efficiency and irrigation reliability.

2.3 Extreme weather events increase agricultural disaster risks

The increasing frequency and intensity of extreme weather events caused by extreme climate conditions constitute an important climatic factor contributing to disaster risks in agricultural production systems. Frequent and destructive extreme weather and climate disasters directly damage agricultural ecosystems, disrupt the normal development and physiological processes of crops, lead to the spread of disasters, weaken disaster resistance and adaptability, and result in reduced yields and income.

In the future, extreme weather events such as extreme heat waves, extreme cold spells, floods, and hailstorms will occur more frequently, causing severe disruptions to crop growth stages. This may result in delayed planting, stress during critical growth periods, and even stunted crop development, creating obstacles. The photosynthesis and material conversion processes of crops will be reduced as a result, directly affecting yield per unit area and overall production safety. In particular, highly sensitive crops such as rice and wheat may experience issues such as pollen sterility, pollination disorders, grain development disorders, lodging, sprouting, or mold during critical growth stages such as heading and flowering, as well as grain filling, due to extreme weather conditions. These issues can be extremely severe, leading to reduced grain yield, lower thousand-grain weight, and even widespread crop failure. Major global grain-producing regions have been impacted by the combined effects of drought and extreme heat, resulting in an average yield reduction of 9–10%, with wheat and corn production declines reaching 12.4% and 8.6%, respectively. Lesk et al. reported that extreme weather disasters reduced global cereal production by 9.9% on average, with wheat and maize experiencing 12.4% and 8.6% yield losses, respectively [4].

To address these challenges, it is necessary to strengthen the prevention of extreme events. Specific measures include establishing a planting system suitable for the climate, increasing research and development efforts for crop varieties with high stress tolerance, setting up intelligent disaster-resistant infrastructure, and strengthening early warning and loss assessment systems for extreme events of all scales. Through these measures, the disaster resistance of the entire agricultural production chain can be comprehensively improved.

2.4 Impact of climate change on the stability of agricultural ecosystems

Climate change not only directly affects crop growth and yield through rising temperatures, changes in precipitation patterns, and extreme weather events, but also profoundly alters the structure and function of agricultural ecosystems in indirect ways, threatening the stability of the system. Agricultural ecosystems are complex systems composed of multiple elements, including crops, pests, natural enemies, soil microorganisms, water resources, and human management activities. Agricultural ecosystems have long relied on ecological balance to maintain stable production and ecological security. However, global warming and abnormal precipitation are disrupting this balance, leading to the following systemic effects.

First, climate warming has caused species phenology to advance, leading to a northward shift in population distribution patterns or expansion to higher elevations, resulting in changes to the composition and interrelationships of regional ecosystems. For example, the expansion of suitable habitats for insects, weeds, and pathogens disrupts the existing balance between natural enemies and pests, triggering new biological invasions and agricultural pest disasters. Additionally, the northward shift of pest overwintering areas, increased generation numbers, and earlier occurrence periods increase the risk of overlap with crop critical growth stages, leading to a decline in the system's self-regulation and control capabilities. Secondly, climate change alters the habitat structure and functional processes of agricultural ecosystems. Frequent high temperatures and droughts lead to the degradation of the ecological functions of farmland wetlands, water sources, and irrigation systems, exacerbate the fragmentation of agricultural landscapes, reduce the stability of crop-predator-host pest networks, weaken system regulatory services, and increase the vulnerability of agricultural production. Furthermore, climate warming significantly affects the composition and function of soil microbial communities. Soil microorganisms are key drivers in maintaining soil fertility, carbon-nitrogen cycles, and crop health. Changes in temperature and moisture induce changes in microbial community structure, weaken soil disease resistance, affect nutrient release rates and fertility stability, and indirectly reduce crop yield and quality. In addition, climate change also leads to an increase in the overall risk level of agricultural pests and diseases, with the frequency, types, and regional structure of pests and diseases becoming more complex. Traditional control systems face the risk of becoming ineffective, increasing the difficulty and cost of agricultural management. Deutsch et al. found that rising temperatures are expected to increase crop losses due to insect pests, especially in temperate regions, where pest metabolic rates and population growth accelerate [5].

Therefore, the stability of agricultural ecosystems should be enhanced through the following measures. First, diverse agricultural landscapes should be constructed, farmland ecological corridors and wetland systems should be restored, and the ecological regulatory capacity of the system should be enhanced. Second, stress-resistant crops, mixed cropping, and ecological agricultural technologies should be applied to enhance the resilience of ecosystems. Third, soil quality management and microbial function regulation should be strengthened. Fourth, establish a regional agricultural ecological monitoring and early warning system to dynamically assess changes in system structure and function, and promptly adjust management measures. By comprehensively enhancing system stability and self-repair capacity, we can ensure the safe development of agricultural production and the coordinated development of the ecological environment.

3. Case Studies

3.1 Impact of Climate Change on Agricultural Production and Food Security in the Mekong Delta, Vietnam

The Mekong Delta is located in Southeast Asia, a region characterized by a typical monsoon climate. It features flat, low-lying terrain and a dense network of rivers, making it the primary rice-producing region in Vietnam and Southeast Asia. The Mekong Delta accounts for over half of Vietnam's total rice production, playing a crucial role in national food security. However, with the impact of global climate change, the region has experienced a sustained rise in temperatures in recent years, abnormal spatial and temporal distribution of precipitation, frequent extreme weather events caused by heavy rainfall, and accelerated sea-level rise, all of which have posed severe challenges to the development of the region's agricultural natural systems. Phuong et al. conducted a comprehensive analysis of the agricultural production patterns and food security status in the Mekong Delta under climate change conditions, based on statistical analysis of meteorological monitoring data and combined with agricultural surveys and interviews [6]. The results indicate that over the past 30 years, the average regional temperature has risen at a rate of 0.4°C/10a, with an increase in the frequency of high-temperature weather events and sudden heavy rainfall events. The reliability of irrigation water supply in rice-growing areas has decreased, and high-temperature stress during the rice flowering and grain filling stages has caused incomplete grain filling, increasing the risk of reduced yields.

Third, the scale of saltwater intrusion caused by sea level rise has expanded, with widespread saltwater intrusion during the dry season's low-water period, exacerbating soil salinization. Traditional freshwater resources have exceeded salt concentration standards, directly impacting rice yields and quality. Research predicts that without adaptive response measures, rice production in the Mekong Delta could decrease by 5%–10% over the next few decades, further reducing the stability of agricultural ecosystems and intensifying challenges to regional food security. In collaboration with local governments and farmers, promote climate-smart technologies, optimize crop planting structures, cultivate salt-tolerant and salt-resistant rice varieties, upgrade water conservancy facilities, and establish a regional water-salt dynamic monitoring and dispatch system. Strengthen public education on climate risks, promote water-saving irrigation and ecological agricultural management practices, and increase agricultural insurance measures to enhance the climate resilience and disaster mitigation capabilities of the region's agricultural system.

3.2 Impact of Rising Temperatures in China's Rice-Growing Regions on Crop Yields and Growth Period Changes

China's rice-growing regions are primarily distributed in the middle and lower reaches of the Yangtze River, South China, and the southeastern coastal areas, playing a crucial role in ensuring national food security. In recent years, driven by the global warming trend, the average annual temperature in China's rice-growing regions has continued to rise, with a significant increase in the frequency of extreme high-temperature weather events. Particularly during the rice grain-filling stage in July and August, high-temperature stress is particularly pronounced, posing a severe threat to the growth process and yield security of rice. Tang et al. conducted a systematic analysis of the mechanisms by which rising temperatures affect the rice production process and yield formation in China's rice-growing regions, based on multi-source meteorological monitoring data and DSSAT crop model simulations [7].

The results indicate that over the past 30 years, the annual average temperature in China's rice-growing regions has risen at a rate of 0.3°C per decade. The accumulation of thermal resources during the rice growing season has increased, and key growth stages such as heading, flowering, and grain filling have generally occurred earlier. The rice growth cycle has shortened, and yield per unit

ISSN 2959-6157

area has shown a declining trend. Especially in late rice production, high-temperature stress has led to accelerated grain filling rates and shorter duration. Insufficient accumulation of photosynthetic products in rice has resulted in inadequate grain filling, directly causing a decrease in thousand-grain weight and reduced grain setting rate. Model simulation results show that for every 1°C increase in temperature, late rice yields will decrease by 8.8%–16.1%, with early rice and single-season rice showing similar trends. More seriously, extremely high-temperature events occurring during the rice heading and flowering period are highly likely to cause pollen sterility and pollination disorders, leading to a significant increase in empty husk rates and exacerbating yield losses. In addition, high temperatures combined with increased pest and disease incidence disrupt the ecological balance of rice paddies and exacerbate production risks. To mitigate the impact of high temperatures, the region has generally adopted measures such as adjusting planting schedules to avoid high-temperature-sensitive periods. Selecting high-quality heat-tolerant varieties, optimizing water and fertilizer management measures, strengthening high-temperature weather warning mechanisms, and implementing dynamic irrigation control can effectively reduce the impact of high temperatures on yield fluctuations. This case study fully validates the role of rising temperatures in the mechanism of rice yield formation. It reveals the sensitivity of rice agriculture in the East Asian monsoon region to high-temperature stress. Additionally, this case study enriches regional climate-adaptive agricultural regulation strategies. This provides an important theoretical basis and practical guidance for ensuring stable agricultural production and food security in rice-growing regions.

4. Conclusion

This study systematically analyzed the core mechanisms through which climate change impacts agricultural development, validating their regional variations using representative case studies of the Mekong Delta in Vietnam and China's rice-growing regions. Rising temperatures directly shorten crop growth cycles and expose critical developmental stages to heat stress, leading to pollen sterility, reduced seed-setting rates, and yield loss. Altered precipitation patterns threaten irrigation water security and field water supply stability, inducing drought or flood stress during crucial water-demand periods. Concurrently, the increased frequency and intensity of extreme weather events directly disrupt agricultural processes, causing widespread yield reduction. Furthermore, global warming indirectly affects agricultural ecosystem stability by shifting phenology, altering pest/disease dynamics, exacerbating landscape fragmentation, and modifying soil microbial functions, thereby weakening system self-regulation.

Case analyses revealed distinct dominant mechanisms across regions. The Mekong Delta faces combined challenges from warming, abnormal precipitation, extreme rainfall, and accelerated sea-level rise, with sea-level rise-induced saltwater intrusion and soil salinization representing a unique and profound impact threatening irrigation sources and land quality. In contrast, China's rice regions highlight the significant inhibitory effect of extreme heat during critical growth stages on yield formation, particularly for late rice in double-cropping systems, alongside increased disease risks. These differences underscore the necessity of location-specific adaptation strategies.

Consequently, the study emphasizes the need for comprehensive adaptation measures: optimizing cropping systems and structures, breeding and promoting stress-resistant varieties, improving field management practices, strengthening infrastructure, enhancing monitoring and early warning systems, boosting ecosystem resilience, supported by public risk education and agricultural insurance policies. Integrating theoretical mechanism analysis with regional case validation, this research provides crucial insights for enhancing the climate resilience and sustainable development of agriculture across diverse regions.

References

[1] IPCC, Climate Change 2022: Impacts, Adaptation, and Vulnerability, Sixth Assessment Report (2022), https://www.ipcc.ch/report/ar6/wg2/.

[2] C. Zhao, B. Liu, S. Piao, et al., Temperature increase reduces global yields of major crops in four independent estimates, Proc. Natl. Acad. Sci. 114 (2017).

[3] J.L. Hatfield, J.H. Prueger, Temperature extremes: Effect on plant growth and development, Weather Clim. Extremes 10 (2015) 4–10.

[4] C. Lesk, P. Rowhani, N. Ramankutty, Influence of extreme weather disasters on global crop production, Nature 529 (2016) 84–87.

[5] C.A. Deutsch, J.J. Tewksbury, M. Tigchelaar, et al., Increase in crop losses to insect pests in a warming climate, Science 361 (2018) 916–919.

[6] N.L. Phuong, T.M. Nguyen, N.T. Le, et al., Impact of climate change on agricultural production and food security: a case study in the Mekong River Delta of Vietnam, Sustainability 16(17) (2024).

[7] Q. Tang, X. Zhang, Y. Li, et al., Comprehensive impacts of climate change on rice production and adaptation strategies in China: A review, Front. Microbiol. 13 (2022).