

Climate Change, Rice Production (*Oryza sativa*), Economic Challenges and Adaptation in the Lower Mississippi River Valley

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Abstract

The specter of climate change impacting the Lower Mississippi River Valley and disrupting agriculture is an ongoing reality. The impact on rice production is a serious concern. This manuscript discusses the impacts of heat stress on rice production and its ramifications in yield and quality assuredness. The critical high temperature liability is largely associated with heat stress induced spikelet sterility at anthesis; however, rice breeding may support rice yield protection and limit quality degradation. Additionally, we investigated selected economic opportunities and challenges, including agricultural policies and crop insurance. With proper farm production adjustments, technology innovation, and enlightened Federal policy, rice production may flourish.

Keywords

Oryza Sativa, High Temperatures, Spikelet Sterility, Rice Breeding, Seed Set, Chalkiness

1. Introduction

Rice (*Oryza sativa*) is a major food source across the human population (United States Department Agriculture, Foreign Agricultural Service, 2026). **Table 1** lists the recent rice production by nation, with India and China the dominant global rice producing nations. Other nations include Bangladesh, Indonesia, Vietnam, Thailand, Philippines, Myanmar, Pakistan, and Cambodia.

The Lower Mississippi River Valley consists of the floodplains and adjacent lowlands of the Mississippi River from southeastern Missouri to eastern Arkansas and Louisiana, and western Mississippi (United States Department Agriculture, 2026). Two rice growing regions in coastal Louisiana and Texas are commonly included in

the Lower Mississippi River Valley geographic collection of rice producing regions, even though they are not connected to the Mississippi River hydrology or aquifer continuum. The United States is not a major rice producing nation; however, the United States is the 4th largest rice exporter (Li et al., 2024a). The key rice producing states are centered in the Lower Mississippi River Valley (along with the coastal regions of Louisiana and Texas) and the central valley of California (Table 2).

Table 1. Leading rice producing nations (2025/2026).

Nation	% Global Production	Production (metric tons-million)
India	28	154
China	27	146
Bangladesh	7	38
Indonesia	6	34
Vietnam	5	26
Thailand	4	21
Philippines	2	12
Myanmar	2	12
Pakistan	2	10
Cambodia	1	8

Source: United States Department Agriculture, Foreign AG. Service.

Table 2. USA rice producing states (2025).

State	Production (metric tons-Millions)
Arkansas	4.73
California	2.28
Louisiana	1.62
Missouri	0.82
Mississippi	0.61
Texas	0.54
United States	10.6

Source—National Agricultural Statistics Service.

Rice production in Lower Mississippi River Valley supports input suppliers, equipment dealers, grain elevators, mills, transportation services, and other agribusinesses throughout the region. In addition to direct economic contribution, rice is important for rural community stability, and agricultural land use. The 2026 Southeast Missouri Rice Planning Budget provides a comprehensive overview of rice production at the farm level. Under the budget assumptions, conventional rice is expected to generate \$792 from rice grain sales, while hybrid rice is expected to generate approximately \$891. Rice production also requires substantial investment in inputs and resources (Brown et al., 2026).

As climate change increases production uncertainty, understanding these farm-level economic relationships becomes important for evaluating the broader con-

sequences of climate impacts on rice-producing communities.

The purpose of this study was to provide a literature-based review focusing on: (i) recent research presenting high temperature influences on rice growth and development, including the impact on spikelet fertility and kernel quality, (ii) estimates of the rice production challenges across the lower Mississippi River valley because of anticipated climate changes, and (iii) an estimate of the economic challenges because of climate change.

2. Manuscript Review Selection Considerations

For selecting references, we identified, evaluated, and synthesize peer-reviewed manuscripts. Manuscripts were selected to showcase only articles published after 2020, with exceptions to allow for seminal research endeavors. The literature selection criteria for inclusion and exclusion and our selection of relevant databases were dictated by our search engines and content focus. Relevant databases included: (i) Agriculture Science Database; (ii) Biological & Agricultural Index; (iii) Agricola; (iv) Web of Science; (v) Google scholar (databases included Jstor, EBSCO, Elsevier, and Science Direct). All journal selections were peer-reviewed and all governmental contributions were internally reviewed by the corresponding agencies. We avoided a large collection of publications whose focus was on (i) methane emissions as a contributor to climate change, and (ii) irrigation management changes to limit aquifer depletion.

Although this manuscript focuses on the United States rice production, most of the rice research occurs in nations across Asia. Additionally, given the similar nature of rice genetics, climate, and production characteristics, then the utilization of Asian references contributes critical information to estimate projected climate change influences.

3. Existing Climate in the Lower Mississippi River Valley

Stoneville Mississippi is in the Mississippi River Delta region and is approximately in the center of the Mid-South rice belt. The mean January temperature is 6°C (42°F) and the mean July temperature is 28°C (82°F). The highest mean monthly temperatures are 32.3°C (89.9°F) for June, 33.5°C (92.3°F) for July and 33.5°C (92.3°F) for August. The highest recorded temperature was 42.8°C (109.0°F) on July 12, 1930 ([Delta Agricultural Weather Data, Mississippi State University Extension, 2026](#)) (Verified August 2026). Weather data archives across the Lower Mississippi River Valley are remarkably similar, whereas the highest monthly mean temperatures are slightly cooler in the northern portion of the rice growing area. As a more southern example, in Baton Rouge, Louisiana, the average monthly high temperatures for May, June, July, and August ranged from 30°C to 33.3°C, respectively ([NOAA National Centers for Environmental Information, 2026](#)) (verified August, 2026). The Louisiana and Texas coastal areas also have slightly lower maximum temperatures because of the moderating effects of the Gulf of Mexico.

The temperature conditions described above are particularly important because rice productivity depends not only on average seasonal temperature but also on

extreme temperatures and duration of exposures. Therefore, understanding how elevated temperatures affect rice at specific developmental stages is essential for evaluating the potential consequences of future climate change.

4. High Temperature Stresses and Their Influence on Rice Growth and Development and Physiology

High temperatures are directly responsible for heat stress in rice. **Table 3** is a reference summary of the influence of high temperatures on various rice growth stages. The intensity of rice yield and quality reductions is influenced by (i) the growth stages of rice, (ii) variety selection, (iii) temperature durations, (iv) time of day, and (v) whether the influence is a measure of yield stability or kernel quality. [Li et al. \(2024a\)](#) predicted that elevated temperatures in California and the Lower Mississippi River Valley in 2040 will reduce rice yields approximately 12 to 25%, with California and the northern portion of the Mississippi delta being more vulnerable. Currently, seasonal air temperatures during grain development are at or above optimum temperature threshold values. Thus, selected regions have experienced seed set reductions.

Table 3. Influence of high temperatures at various growth stages.

Rice Growth Stage	Influence of High Temperatures	Temperature Intervals
Germination Establishment	Reduced seed germination and seed vigor, decline in plasma membrane thermostability,	Optimum 25 - 28°C
Tiller Development	Reduced tiller number and biomass (more influence in japonica than indica).	Optimum 25°C (daytime) and 20°C at nighttime. Above 33°C damaged tillering
Spikelet Development	Sterility largely attributed to impaired pollen, anther dehiscence, stigma germination and inadequate pollen tube elongation.	Optimum temperatures are 23 to 26°C. Yields decline > 33°C
Pre-flowering and Anthesis	Pre-flowering panicles reduced, distortion of floral organs (size and quantity). Embryo abortion and alteration of pollen proteins. Microspore stage after meiosis is most susceptible, (39°C daytime, 30°C nighttime). Reduced anther dehiscence. Reduced seed set at 35°C for five days. Elevated temperatures inhibit carbohydrate transport to pollen, reduce viable pollen grains on stigmas.	Pre-flowering high temperature stress at 40°C (daytime), 35°C (nighttime) when compared to standard temperatures of 28°C
Grain Filling	Reduced grain weight is attributed to impaired assimilate production associated with reduced photosynthesis and accelerated senescence. Enzymes for starch production are inhibited. Inactivation of Rubisco activase (ribulose-1, 5-bisphosphate carboxylase/oxygenase)	Chalkiness increases when temperatures are greater than 20°C (medium-maturing) or greater than 30°C (late-maturing)

Source: [Kalaichelvi et al. \(2025\)](#); [Liu et al. \(2023\)](#); [Xu et al. \(2021\)](#); [Yu et al. \(2025\)](#); [Ren et al. \(2023\)](#); [Jian et al. \(2026\)](#); [Gauthier et al. \(2026\)](#).

Using modern rice production records, archaeological data, and temperature projections, [Gauthier et al. \(2026\)](#), on a global scale, determined that sustained Asian rice production rarely survived temperatures greater than 33°C. They defined rice thermal limits using maximum annual temperatures, maximum temperatures of the warmest month, and maximum temperature of the warmest quarter and proposed that an appreciable proportion of Asian's rice producing regions will experience extensive contraction.

[Jian et al. \(2026\)](#) utilized field-warming experiments and analyzed rice yield responses at various growth stages and determined that harvest index reductions started at 30°C. Rice yield reductions were 1.1% to 1.8% for a one-day exposure if the critical temperature was more than 30°C for a one-day exposure. [Xu et al. \(2021\)](#) supported the premise that an 8.1% global rice yield loss per 1°C of warming is possible, impacting global food security. [Kalaichelvi et al. \(2025\)](#) noted that 20th century climate change featured a 0.5°C increase in air temperature and 21st century projections estimate a rise of 1.5 to 4.5°C. [Xu et al. \(2021\)](#) reported that a single day above 30°C during the rice reproductive stage likely causes a 1.1% to 1.8% yield loss.

[Esquerra et al. \(2019\)](#) reported a field trial showing that at flag-leaf collar high nighttime temperatures reduce spikelet fertility in susceptible varieties. [Kalaichelvi et al. \(2025\)](#) reported that temperatures above 33°C decreased rice production in various regions of the world. High temperature stress negatively influenced seed germination, reductions in tiller number and biomass, and spikelet (pollen) sterility. High temperature stress adversely influenced seed set, seed weight accumulation and altering carbohydrate metabolism. [Kalaichelvi et al. \(2025\)](#) reported that the optimum temperature for tillering is 25°C during the day and 20°C at night. Tillers increased with increasing temperature in the range of 15°C to 33°C. [Gauthier et al. \(2026\)](#) determined that optimum rice temperatures center around 23°C to 26°C, and yield declines are predictably favored when temperatures are greater than 33°C.

[Liu et al. \(2023\)](#) defined the critical high temperature thresholds for seed set in rice ($37.2^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$) during flowering. Heat stress influences spikelet opening, anther dehiscence, pollen shedding number, pollen viability, pistil and stigma function, pollen germination and pollen tube elongation. However, breeding for lower canopy/tissue temperatures compared to air temperatures may protect rice from heat damage. [Shrestha et al. \(2022\)](#) documented that heat stress is manifested by an increased spikelet sterility and reduced grain yield. Rice growth and development are compromised by pollination restrictions because of distorted floral organs, tapetum degeneration, low pollen protein concentrations and viability, reduction in anther dehiscence, low pollen dispersal, and decreased stigma pollen density. Reduced grain yield is related to reduced photosynthetic rates, increased functional leaf senescence and starch synthesis.

[Hu et al. \(2021a\)](#) reported the effects of heat stress on anther development, noting (i) cellular and structural deficiencies, including tapetal cells that fail to de-

generate, (ii) pollen and fertility effects because microspores become distorted pollen grains and anthers fail to release pollen onto the stigma, (iii) yield loss because heat-sensitive rice varieties experience reduced grain yield and poorly developed seeds. [Krishnan et al. \(2011\)](#) noted the following heat-stress responses during rice cultivation, (i) reduced post-germination growth, plant height, (ii) limits normal tillering, total dry matter accumulation, and damages root functions, (iii) spikelet differentiation fails, pollen viability drops, and anther dehiscence is compromised. During flowering, spikelet sterility occurs at temperatures greater than 35°C. Elevated nighttime temperatures increase respiration, reducing net photosynthesis. Heat stress shortens the grain-filling period and hinders starch synthesis enzymes and alters protein accumulation.

[Su et al. \(2023\)](#) conducted a meta-analysis assessing the influence of high daytime and high nighttime temperatures on panicle number, spikelet number per panicle, percent fertility, grain weight and quality traits, including milling yield, chalkiness, amylose and protein contents. Compared to high daytime temperatures, high nighttime temperatures negatively impacted rice yield and quality. The optimum daytime and nighttime temperatures for production were 28°C and 22°C, respectively. The seed set rate was the most sensitive yield component for both high daytime and nighttime temperatures, followed by chalkiness and head rice percentage. Rice chalkiness is an opaque and whitish colored milled rice grain, which occurs because starch and protein granules are loosely packed and are separated by air spaces that scatter light. [Yu et al. \(2025\)](#) noted that chalkiness was negatively influenced by elevated temperatures. The most critical climatic factors influencing chalkiness in medium-maturing rice as temperatures above 20°C during the grain-filling period and for late-maturing rice, temperatures above 30°C during the grain-filling period. [Uddling et al. \(2018\)](#) noted that crops cultured under enhanced CO₂ typically manifest increased yields also show reduced nutritional quality. [Hu et al. \(2021b\)](#) discussed how elevated temperature inhibit enhanced carbon dioxide support for photosynthesis

Head rice is the amount of whole unbroken kernels (>75% of kernel length) of milled rice. Head rice recovery is the ratio of head rice to total paddy rice weight. Typically head rice recovery is 25% to 65%. Heat stress manifests itself as organ disfunction and grain quality reductions. [Ali et al. \(2026\)](#) imposed day and nighttime temperatures (31°C/23°C) on various varieties during late grain filling and noted that elevated temperatures supported reduced head rice yields and head rice yield reductions were variety dependent. [Zhou et al. \(2024\)](#) investigated multiple rice varieties for high temperature heat stress. Most rice varieties exhibited increased levels of amylose, chalky degree and protein content, cracked grains and suppressed amino acid levels. High temperature stress also increased Mg, K, P, S, Cu, Zn, and Mo in the rice flour.

The physiological responses described above provide the basis for evaluating the potential regional consequences of climate change. Heat-induced reductions in pollen viability, spikelet fertility, seed set, grain filling, and milling quality can

ultimately translate into lower marketable rice production. However, the magnitude of these effects, will eventually depend on temperature changes, changes in precipitation, atmospheric carbon dioxide, and producer adaptation. The following section therefore considers projected changes in rice production across the Lower Mississippi River Valley.

5. Anticipated Changes in Rice Production across the Lower Mississippi River Valley

Climate projections indicate that temperatures across the Lower Mississippi River Valley are likely to increase during the twenty-first century. In a review, [Walthall et al. \(2013\)](#) find that if CO₂ atmospheric concentrations increase to approximately 550 ppm, then global average surface temperatures increase to 1.1°C to 2.9°C in 2100. If CO₂ atmospheric concentration increases to approximately 800 ppm, then global average surface temperatures increase to 2.0°C to 5.4°C by 2100. Although these projections represent global averages rather than conditions specific to the Lower Mississippi River Valley, they provide a useful basis for understanding the potential magnitude of future warming.

[Li et al. \(2024b\)](#) evaluated climate simulation models and for 2040 projected a temperature increase of 1°C to 3.5°C along the Gulf Coast and a temperature increase of 1.5°C to 5.5°C in the State of Mississippi Delta region. Performing a meta-analysis of climate simulation models, [Li et al. \(2024a\)](#) reported on the predicted impacts of future climate change on rice yields and rice physiology. Their analysis proposed that (i) rice yields would decrease with increasing average temperatures, (ii) if precipitation changed between 0% and 25%, then rice production will not become negatively influenced, and (iii) elevated CO₂ concentrations and management practices could mitigate a significant portion of the negative effects attributed to climate change.

The projected increase in temperature is expected to place downward pressure on rice yields in many areas. [Li et al. \(2024a\)](#), using evidence from rice-producing regions in the United States, including California and the Lower Mississippi River Valley, estimated that rice yields could decline by approximately 12% to 25% under projected 2040 temperature conditions. Higher temperatures can directly impair reproductive processes, accelerate crop development, and reduce grain quality, while extreme heat events may exceed the physiological capacity of plants to benefit from additional CO₂. [Sharma et al. \(2022\)](#) simulated the influence of anticipated climatic variables on major cereal crops, including rice. Rainfall did not alter rice yields. A predicted 1°C rise in the maximum temperature decreased rice yields (8.30%); however, a 1°C increase in minimum temperature increased rice yields (22.40%).

Future atmospheric CO₂ concentrations may partially offset some of the negative effects of higher temperatures. Elevated CO₂ can increase photosynthesis and biomass production and may therefore provide some compensation for climate-related yield losses. [Li et al. \(2024b\)](#) estimated that elevated CO₂ could compensate

for approximately 18% to 42% of yield losses associated with reductions in spikelet fertility. However, the potential benefits of elevated CO₂ should not be interpreted as eliminating the risks associated with warming. [Dubey et al. \(2018\)](#) similarly noted that warming could diminish or eliminate some of the productivity benefits associated with elevated CO₂. An economic study across the Lower Mississippi River valley estimated that yields of rice and cotton would decrease from climate change; however, increase acreage plantings will offset the yield reductions ([Xie et al., 2019](#)).

These projected changes have important economic implications for rice-producing farms. Lower or more variable yields can affect production costs per unit of output, farm revenue, profitability, and income stability. Thus, the regional production effects of climate change ultimately translate into farm-level economic risks and adaptation decisions. The following section examines these policy and economic challenges, with particular attention to climate adaptation and crop insurance as mechanisms for managing increasing production and income risk.

6. Understanding the Existing and Anticipated Policy and Economic Challenges

As explained above, climate change can have significant adverse effects on rice yields through rising temperatures and changes in precipitation patterns. Under the 2026 Southeast Missouri Rice Planning Budget, rice generates enough revenue to cover operating costs but not enough to cover all economic costs. This creates a relatively narrow profitability margin ([Brown et al., 2026](#)). If climate change reduces yields or grain quality, or increases irrigation, fertilizer, crop protection, or other production costs, the reduction in revenue could further reduce returns to land and management.

Declining and increasingly variable yields can substantially reduce farm income and reduce livelihoods, food security, and overall welfare of rice farmers. These impacts may be particularly severe for smallholder farmers who have limited financial resources and fewer opportunities to absorb or recover from production losses. Such measures may include adopting climate-resilient practices using risk-management tools such as crop insurance. Hence, farmers can reduce their vulnerability to climate-related production shocks and improve their ability to maintain farm income and welfare under changing climatic conditions.

6.1. Climate Adaptation

Climate change can simultaneously affect yields, production costs, revenue, and income variability, farmers may need to adjust both their production practices and their risk-management strategies. Adaptation can therefore be viewed not simply as a means of maintaining biological yield, but as an economic decision aimed at improving farm resilience while maintaining profitability. The following section examines several adaptation strategies and their potential economic consequences ([Marvel, 2023](#)).

Climate change can increase vulnerability in food production and threaten farm livelihoods. Consequently, adaptation strategies that enhance the resilience of agricultural production while maintaining farmer profitability and food security are becoming increasingly important. Evidence from rice-producing regions demonstrates that climate adaptation can generate measurable economic benefits (Isik & Devadoss, 2006; Ho & Shimada, 2021). Producers may respond through heat and drought tolerant varieties, adjustments in planting dates, improved irrigation and water-management practices, enhancing nitrogen-use efficiency and increasing crop diversification. Dhakal et al. (2022) find that climate change adaptation leads to a 21.6% increase in farm revenue and a 6.4% reduction in downside risk exposure.

Farmers don't select crops based only on their expected yield or profit potential, they also consider profit uncertainty and how different crops perform relative to each other. This is particularly important because the Lower Mississippi River Valley is not just a rice producing region. Farmers can potentially allocate land among rice, soybeans, corn, cotton, and other crops (Isik & Devadoss, 2006). If climate change makes rice relatively less attractive compared with competing crops, the long-run consequence may be reduced rice acreage, even if rice remains biologically viable in the region. According to Deschênes & Greenstone (2007), lower yield does not always mean lower land value for farmers as they may change inputs to adapt to higher temperatures or may find a better and more productive use for it other than agriculture.

In a study by Ho & Shimada (2021), rice farmers in Vietnam's Mekong Delta were surveyed and it was found that adaptation strategies addressing drought and salinity intrusion generally improved rice yield, profitability, and household income while reducing chemical fertilizer use. For example, a study of Crop-management adaptation strategies increased rice yield by approximately 13%, profitability by 14%, and household income by 19%, while reducing chemical fertilizer use by 7%. Importantly, the study found that more comprehensive adaptation packages did not necessarily generate greater profitability, even when they produced higher yields and household income. This suggests that farmers' climate adaptation involves high production and trade-offs among productivity, profitability, and income stability.

Increasing agricultural diversity and chemical environmental management can improve yield and income stability in distressing times (Harkness et al., 2023). Income diversification also increased household income by approximately 25% (Ho & Shimada, 2021). Fabri et al. (2024) studied Italian farmers and discovered that crop specialization may generate higher expected income, whereas crop diversification can substantially reduce income risk (Fabri et al., 2024). Particularly, it finds that cultivating four different crops was associated with an approximately twenty-nine percent reduction in income risk compared with monoculture. Common Agricultural Policy has been introduced by the European Union to encourage agricultural diversification. Brutti, Freo, & Serlenga (2025) noted that because

of this policy crop diversity grew approximately 0.62 greater than it would have been without the policy across 28 member states and reduced the concentration of land in dominant crops. However, [Fabri et al. \(2024\)](#) state that the greening payments from this policy may not fully compensate farmers for the potential reduction in expected crop income resulting from diversification.

However, different farms experience climate change differently. Therefore, agricultural policies designed to reduce income and production risk should be flexible and tailored to different farms. Farmers might respond to heat or drought by increasing irrigation or chemical inputs. These actions could stabilize production in the short run but potentially create environmental problems. Climate adaptation policies should not focus solely on maintaining yields under increasing temperatures but should also consider the cost-effectiveness of adaptation, producer profitability, income stability, and environmental consequences.

Climate change will considerably increase the production and income risk of farmers. With an increase in temperature, rainfall becomes less reliable and yield becomes less consistent. Variability in temperature and rainfall reduces the stability of farm income and food production ([Harkness et al., 2023](#)). As weather becomes extreme, there is greater variability in farm income which can expose a greater number of households in absolute poverty ([Binswanger et al., 1993](#); [Dercon & Christiaensen, 2011](#)). As climate change becomes more severe, evaluating the adequacy of existing policies will become increasingly important for sustaining rice production and farm incomes in the Lower Mississippi River Valley.

Climate change can impact farmers' yields, revenue, costs and ultimately profits. Farmer profitability is one of the most appropriate indicators of farmer welfare ([Deschênes & Greenstone, 2007](#)). Land value is another indicator of farmer welfare that can be impacted by climate change ([Deschênes & Greenstone, 2007](#)). To safeguard their interests, farmers may respond (i) by adopting production practices to meet climate changes, or (ii) by insuring their yield or revenue against losses.

6.2. Crop Insurance

In time of distress and climate change, crop insurance can play an important role in sustaining farmers' livelihoods and overcoming downside income risk. [Table 3](#) lists the major types of United States Federal crop insurance programs that farmers can avail to overcome losses from weather hazards.

The insurance schemes listed in [Table 4](#) involve different principles and provide considerable flexibility to farmers to adjust the coverage based on their needs, their production choices, the amount of premium they can afford, and the extent of coverage they need. Insurance programs that safeguard yield or use area-based index can protect against weather related hazards, whereas those that safeguard overall revenues of the farm can allow farmers to diversify their production. Evidence suggests that conservation practices such as cover crops can reduce crop-insurance losses associated with drought, excess heat, and excess moisture, indi-

cating that insurance and climate-resilient production practices can potentially complement one another (Aglasan et al., 2024).

Table 4. Major types of federal crop insurance available to U.S. producers.

Insurance Type	How it works	Example
Yield Insurance	Establishes an expected/insured yield based largely on the farm's historical production (5 - 10 years). The producer receives an indemnity when the actual yield falls below the insured yield. Because of the insured cause of loss. It protects against climate-related yield loss, such as drought, excessive heat, flooding, or other covered weather events.	Actual Production History (APH), Yield Protection (YP)
Revenue Insurance	Combines an insured production level with a commodity price to establish a revenue guarantee. The producer receives an indemnity when actual revenue falls below the guarantee. It protects against loss of crop revenue caused by low yield, low price, or both.	Revenue Protection (RP)
Area/Index Insurance	Useful for widespread climate events such as regional drought, heat waves, or flooding, which may affect may producers simultaneously.	Area Risk Protection Insurance (ARPI)
Whole-Farm Insurance	Instead of insuring one crop, the policy considers overall revenue from multiple commodities produced on the farm. This allows diversified farms to ensure their overall revenue if revenue falls below the insured revenue guarantee. This is particularly relevant to diversification as a climate adoption strategy.	Whole-Farm Revenue Protection (WFRP)
Margin Insurance	The policy considers both revenue and input costs. A producer can experience a loss when crop revenue declines, input costs increase, or both occur simultaneously.	Margin Coverage Option (MCO)

Source: Authors' compilation based on USDA Risk Management Agency and U.S. Department of Agriculture, Economic Research Service (2026).

On the other hand, insurance programs may alter the financial incentives that shape the production decisions. Subsidized crop insurance can also create moral hazard, whereby producers have weaker incentives to adopt costly risk-reducing or environmentally beneficial practices. Annan & Schlenker (2015) studied a highly subsidized crop insurance program for corn and soybean farmers and found that dependence on such programs can make farmers more vulnerable to climate change, and less willing to adapt. It finds that for insured corn farmers there was 67% more sensitivity to extreme heat as compared to uninsured corn farmers, and for insured soybean farmers there was 43% more sensitivity to extreme heat as compared to uninsured soybean farmers. An unintended consequence that can arise from crop insurance is inefficient allocation of land (Smith & Goodwin, 2013). Subsidized crop insurance can influence crop choice and land

use; whereby less productive land is brought under cultivation because there is a promise that losses will be compensated.

7. Prospects for Agricultural Climate Change Mitigation

As climate change is likely to affect crop productivity, production costs, markets, and farm income in different ways across regions and production systems, farmers must make decisions under considerable uncertainty. In the case of rice production, these uncertainties can result in greater variability in yields and revenues, making it increasingly important for farmers to strengthen their capacity to manage production and financial risks. Adaptation, therefore, should extend beyond changes in production practices and may require a combination of technological, agronomic, economic, and institutional strategies.

Predicting the influence of climate change on regional agriculture is hindered by numerous suppositions. These assumptions include: (i) climate models are evolving technologies, (ii) livestock, crops, turfgrass and other agriculture/horticulture industries will be influenced differently, (iii) negative impact in one agricultural sector may influence other agricultural sectors or regions, (iv) emerging technologies may alter agricultural productivity, (v) agribusiness responses may not be effective, (vi) trade and marketing will influence production distribution and price, (vii) difficulty in predicting plant diseases, weed management, soil fertility programming, (viii) effectiveness of integrated pest management, (ix) continuation of appropriate research, and (x) variety development. Economic impacts may include: (i) agribusiness ability to forecast and implement programs that consider climate change, (ii) changes in producer and consumer behavior, (iii) potential to adapt technologies or anticipate constraints on agricultural production, (iv) difficulty in anticipating adjustment of transition costs (Walthall et al., 2013).

Climate change will influence numerous aspects of agriculture, including water resources and irrigation management (Reba et al., 2017; Aide, 2019; Aide & De Guzman, 2020). These authors chronicled that alternate wetting and drying irrigation and furrow irrigation systems promise to reduce water usage and improve water use efficiency. Thus, irrigation technologies may reduce the potential tendency for rice to deplete water resources. Ding et al. (2026) investigated future global aspects of drought and temperature. North American rice production will likely experience substantial drought exposures, whereas Southeast Asia will experience extreme rainfall events, supporting increased crop lodging and root diseases. Srivastav et al. (2021) proposed that climate change-resistant crop development, improved water/irrigation management, adapting climate-smart agriculture protocols are integral activities to meet emerging climate change challenges.

Yang et al. (2022) noted that rice shows a weak adaptation to global climate change, indicating that rice may not have the genetic diversity to respond to future climate change. Currently, rice production has not utilized technologies involving genetically modified organisms; however, critical rice production shortfalls may alter this research orientation. Technologies involving precision agriculture, espe-

cially with combined with emerging remote sensing systems and real-time production management software is likely to foster climate-smart agriculture.

Li et al. (2024b) predicted that the Gulf Coast will experience less yield loss than the Mississippi Delta and California. However, an emerging production issue involves increased salinity in both surface and groundwater resources, especially along the Gulf of Mexico. Ziska et al. (2018) proposed that increased rice ratooning may provide additional rice production. In Missouri land suitable for rice production and its associated groundwater resources will permit rice land area expansion, without increasing aquifer depletion. Conversely, rice production in the Grand Prairie region (Arkansas) currently is experiencing aquifer depletion.

8. Conclusion

In many areas of the Lower Mississippi River Valley, critical high temperatures threaten to increase the incidence of rice spikelet sterility, leading to reduced yields. Additionally reduced quality associated with head rice and chalkiness will reduce the market receptiveness of rice. The rice literature has listed the critical temperature for inducing spikelet sterility, which varies across the literature from 30°C to 37°C. Regardless of which temperature is most appropriate, the current high temperature indicators across the Lower Mississippi River Valley indicate that spikelet sterility induction is a major concern and with climate change predictions the concern will increase. Rice breeding programs offer the promise of alleviating a portion of the climate change influence.

As climate change progresses, fluctuations in temperature and rainfall may become more important sources of uncertainty for farmers. Producers may face not only lower average yields, but also greater year-to-year variation in yields and farm income. Different farms will experience climate change differently. Therefore, agricultural policies designed to support farm income and minimize production risk should be flexible and tailored to different production systems. Agricultural production should not come at the expense of the environment. For example, farmers might respond to heat or drought by increasing irrigation or chemical inputs. These actions could stabilize production in the short run but potentially create environmental problems. Therefore, adaptation needs to consider both economic resilience and environmental sustainability.

Author Contributions

Aide, M., Primary Author.

Ijaz, A, design and wrote section on economics (section 6.1 to end of 6.2).

Nakasagga, S., provided information on breeding and effects of temperature on spikelet fertility.

All authors characterized the manuscript orientation and writing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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