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IMPACT OF CLIMATE CHANGE ON AGRICULTURAL INCOME: AN EMPIRICAL ANALYSIS OF FARMERS IN KERALA

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Abstract

Climate change poses significant challenges to agricultural productivity, farm income, food security, and rural livelihoods in Kerala. This study examines the impact of climate variability on agricultural income among farmers, focusing on changes in temperature, rainfall, extreme weather events, and seasonal uncertainty. The study adopts an empirical research design based on primary and secondary data. Primary data were collected from 200 farmers across different districts of Kerala using a structured questionnaire covering climate perceptions, agricultural productivity, production costs, farm income, adaptation practices, and institutional support. Secondary data were obtained from government departments, agricultural institutions, international organisations, and published research. Percentage analysis, correlation analysis, and multiple regression analysis were employed to examine the relationships between climate variability, agricultural productivity, and farm income. The findings indicate that climate variability significantly affects agricultural income through changes in productivity, production costs, resource availability, and market conditions. The study highlights the need for effective policy support, climate-resilient technologies, financial assistance, and agricultural extension services to strengthen farmers' adaptive capacity, income security, and livelihood resilience in Kerala.

Keywords: *climate change, agricultural income, climate variability, farmers, agricultural productivity, climate adaptation, kerala.*

JEL Classification: *Q12, Q15, Q18, Q54, O13.*

Introduction

Climate change has emerged as a major environmental and economic challenge, significantly affecting agricultural production, food security, rural livelihoods, and sustainable development. Rising temperatures, changing rainfall patterns, floods, droughts, and other extreme weather events directly influence crop productivity, production costs, resource availability, and agricultural income. Since agriculture is highly dependent on climatic conditions, farmers are particularly vulnerable to increasing climate variability.

Agriculture remains an important sector of the Indian economy, supporting employment, food security, and rural development. Kerala has a diverse agricultural system comprising plantation crops such as rubber, coconut, pepper, tea, coffee, and cardamom, along with food crops such as paddy, banana, tapioca, and vegetables. However, the state's agriculture is increasingly vulnerable to irregular monsoons, rising temperatures, floods, droughts, landslides, and intense rainfall events. These climatic changes have contributed to fluctuations in crop yields, increased production costs, and instability in farmers' income, particularly among small and marginal farmers.

Various government programmes, including the National Mission for Sustainable Agriculture (NMSA), Pradhan Mantri Fasal Bima Yojana (PMFBY), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), and climate-resilient agricultural initiatives, aim to strengthen farmers' adaptive capacity and reduce climate-related risks. However, challenges related to access to irrigation, credit, technology, insurance, and institutional support continue to affect farmers' resilience.

Against this backdrop, the present study examines the impact of climate change on agricultural income among farmers in Kerala by analysing the relationship between climate variability, agricultural productivity, adaptation strategies, socio-economic characteristics, institutional support, and farm income. The study also identifies the major determinants of income vulnerability and evaluates the role of adaptation measures and government interventions in strengthening farmers' resilience and promoting sustainable agricultural development in Kerala.

Review of Literature

Several scholars have examined the relationship between climate change and agriculture from the perspectives of environmental economics, agricultural economics, climate science, rural development, and sustainable livelihoods. Early studies primarily focused on measuring the effects of climate variability on crop production, whereas recent research increasingly integrates climate adaptation, income resilience, technological innovation, institutional support, and policy interventions. Researchers argue that climate change not only affects agricultural productivity but also significantly influences farmers' income, livelihood security, food security, and rural economic sustainability.

William D. Nordhaus (1991; 1994) was among the earliest economists to analyse the economic consequences of climate change. His integrated assessment models demonstrated that changes in temperature and precipitation have significant implications for agricultural productivity, economic welfare, and resource allocation. Nordhaus argued that climate change imposes long-term economic costs on agriculture, particularly in climate-sensitive regions, highlighting the need for effective adaptation policies.

Robert Mendelsohn, William Nordhaus, and Daigee Shaw (1994) introduced the Ricardian Approach to estimate the economic impact of climate change on agriculture. Their study showed that variations in climate directly influence land values and farm income by affecting crop productivity and production decisions. The Ricardian model has since become one of the most widely adopted approaches for analysing climate impacts on agricultural income.

Robert Mendelsohn (2001) further examined farmers' adaptive behaviour under changing climatic conditions. He argued that farmers respond to climate variability through crop diversification, technological adoption, irrigation, and improved farm management practices. His work demonstrated that adaptation substantially reduces income losses associated with climate change and improves long-term agricultural sustainability.

David B. Lobell and Christopher B. Field (2007) investigated the influence of climate trends on global agricultural production. Their research revealed that increasing temperatures and changing rainfall patterns have significantly reduced yields of major food crops in many developing

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countries. They concluded that climate variability has direct implications for farm profitability, food security, and rural incomes.

Intergovernmental Panel on Climate Change (IPCC) (2014; 2022) provided comprehensive assessments of climate change and its implications for agriculture. The reports highlighted that rising temperatures, erratic rainfall, floods, droughts, and extreme weather events have become major threats to agricultural productivity and farmers' livelihoods. The IPCC emphasised the importance of climate-resilient agriculture, sustainable resource management, technological innovation, and institutional support in strengthening farmers' adaptive capacity.

Gerald C. Nelson et al. (2010) analysed the effects of climate change on global food production and agricultural markets. Their study projected significant reductions in crop yields and farm income under different climate scenarios while emphasising that investments in agricultural research, irrigation, and technological innovation can mitigate adverse economic impacts.

Shenggen Fan and Mark W. Rosegrant (2008) examined the relationship between climate change, agricultural productivity, and rural poverty. Their research demonstrated that declining agricultural productivity resulting from climate variability disproportionately affects smallholder farmers by reducing income, employment opportunities, and household food security. They stressed the importance of public investment in climate adaptation and rural infrastructure.

R. K. Mall, Akhilesh Gupta, Ranjeet Singh, L. S. Rathore, and R. S. Singh (2006) investigated the vulnerability of Indian agriculture to climate change. Their findings indicated that increasing temperatures, irregular monsoons, and changing rainfall patterns significantly affect crop productivity across different agro-climatic regions of India. The study recommended the adoption of climate-resilient technologies and improved water management practices.

S. K. Sinha and M. S. Swaminathan (1991) highlighted the vulnerability of Indian agriculture to climatic variability. Their research demonstrated that changing climatic conditions influence crop yields, production risks, and farmers' income, particularly among small and marginal farmers. They advocated sustainable agricultural practices and technological innovations to enhance resilience.

N. H. Ravindranath, I. K. Murthy, and colleagues (2011) assessed climate change vulnerability across Indian states. Their study identified Kerala as one of the highly climate-sensitive states due to its dependence on monsoon rainfall, plantation agriculture, and fragile ecosystems. They emphasised the need for region-specific climate adaptation strategies to sustain agricultural productivity and income.

Swaminathan, M. S. (2012) argued that climate-smart agriculture is essential for ensuring food security and improving farmers' livelihoods under changing climatic conditions. He emphasised integrated farming systems, efficient water management, improved crop varieties, and institutional support as key determinants of income resilience.

Mahendra Dev, S (2012; 2018) examined climate change and rural livelihoods in India. His studies showed that climate-induced production instability adversely affects agricultural income, employment, and poverty reduction efforts. He highlighted the importance of crop insurance, rural credit, agricultural extension, and social protection programmes in reducing farmers' vulnerability.

Government of Kerala (2021–2024), through the *Economic Review*, documented increasing climate-related challenges such as floods, droughts, landslides, irregular rainfall, and rising temperatures affecting agricultural production in the state. The reports indicated that climate variability has substantially influenced plantation crops, paddy cultivation, coconut production, and overall farm income, underscoring the need for sustainable and climate-resilient agricultural practices.

National Bank for Agriculture and Rural Development (NABARD) (2022) reported that climate-resilient agriculture, micro-irrigation, watershed development, financial

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inclusion, and institutional credit significantly improve farmers' adaptive capacity and income stability. The study recommended strengthening climate finance and rural infrastructure to enhance agricultural resilience.

Food and Agriculture Organisation (FAO) (2013; 2021) promoted the concept of Climate-Smart Agriculture (CSA), emphasising increased agricultural productivity, adaptation to climate change, and reduction of greenhouse gas emissions. FAO highlighted that CSA practices contribute to higher farm income, improved resource efficiency, and sustainable rural development.

Recent studies (2020–2025) increasingly employ econometric techniques, panel data analysis, spatial analysis, Geographic Information Systems (GIS), remote sensing, machine learning, and climate modelling to analyse the relationship between climate variability and agricultural income. These approaches facilitate more accurate estimation of climate impacts, identification of vulnerable regions, assessment of adaptation strategies, and formulation of evidence-based agricultural policies.

Recent scholarship indicates that integrating environmental economics, agricultural economics, climate science, and rural development provides a more comprehensive understanding of climate change and agricultural income. Researchers increasingly emphasise that agricultural income is influenced not only by climatic variables but also by socio-economic characteristics, institutional support, technological adoption, market conditions, and government policies.

Although considerable research has been conducted on climate change, agricultural productivity, and climate adaptation, relatively fewer studies comprehensively integrate climatic variables, adaptation strategies, socio-economic factors, institutional support, and agricultural income within a unified empirical framework focusing specifically on Kerala. Existing research often analyses productivity or climate vulnerability independently, while comparatively limited attention has been devoted to examining how climate variability, adaptive capacity, technological adoption, government interventions, and household characteristics collectively determine agricultural income.

The present study seeks to bridge this research gap by providing a comprehensive empirical analysis of the impact of climate change on agricultural income among farmers in Kerala. The study integrates perspectives from environmental economics, agricultural economics, climate science, sustainable agriculture, and rural development to examine how climate variability affects farm income and how adaptation strategies and institutional support contribute to income resilience and sustainable agricultural development.

Theoretical Review

Climate Change Adaptation Theory: Climate Change Adaptation Theory explains how individuals, households, and farming communities adjust their agricultural practices in response to changing climatic conditions. Adaptation measures include crop diversification, improved irrigation, climate-resilient crop varieties, integrated farming systems, soil and water conservation, and adoption of modern agricultural technologies. The theory suggests that effective adaptation enhances farmers' resilience, reduces production risks, and improves agricultural income under climate uncertainty.

Sustainable Livelihoods Framework (SLF): The Sustainable Livelihoods Framework, developed by the UK Department for International Development (DFID), explains how households utilise different forms of capital, human, natural, financial, physical, and social, to sustain their livelihoods. The framework argues that climate change affects these livelihood assets, influencing agricultural productivity and income. Strengthening institutional support, infrastructure, and adaptive capacity enhances livelihood resilience and income security.

Ricardian Theory of Climate Change and Agriculture: The Ricardian Theory, developed by Mendelsohn, Nordhaus, and Shaw (1994), examines the relationship between climate variables and agricultural land values or farm income. It assumes that land values reflect the long-term profitability of agriculture under prevailing climatic conditions. The approach estimates how changes in temperature and rainfall influence agricultural income while accounting for farmers' adaptive responses. It remains one of the most widely used theoretical frameworks in empirical climate–agriculture research.

Human Capital Theory: Human Capital Theory emphasises that education, knowledge, farming experience, technical skills, and access to agricultural extension services improve farmers' ability to adopt climate-resilient technologies and innovative farming practices. Farmers with higher levels of human capital are generally better equipped to respond to climate variability, enhance productivity, and maintain stable agricultural income.

Climate-Smart Agriculture (CSA) Framework: Climate-Smart Agriculture promotes agricultural practices that simultaneously increase productivity, strengthen resilience to climate change, and reduce environmental impacts. The framework advocates efficient resource management, sustainable farming techniques, improved crop varieties, water conservation, renewable energy, and digital agricultural technologies. Adoption of CSA practices contributes to higher agricultural income, greater climate resilience, and long-term sustainability.

Vulnerability Theory: Vulnerability Theory explains that the impact of climate change depends on three interrelated dimensions: exposure to climate hazards, sensitivity of agricultural systems, and adaptive capacity of farmers. Small and marginal farmers are generally more vulnerable because of limited financial resources, inadequate irrigation, restricted access to technology, and weak institutional support. Reducing vulnerability through policy interventions and adaptation measures enhances income stability and livelihood resilience.

Objectives of the Study

1. To examine the impact of climate change variables, including temperature variation, rainfall variability, and extreme weather

events, on the agricultural income of farmers in Kerala.

2. To analyse the relationship between climate change, agricultural productivity, crop yield, production costs, and farmers' income across different agricultural regions of Kerala.

3. To investigate the influence of socio-economic characteristics, farm size, cropping pattern, irrigation facilities, technological adoption, and institutional support on farmers' ability to adapt to climate change.

4. To assess the effectiveness of climate change adaptation strategies, including crop diversification, climate-resilient agricultural practices, irrigation management, crop insurance, and government support programmes, in improving agricultural income and livelihood resilience.

5. To suggest appropriate policy measures and climate-resilient agricultural strategies for enhancing farmers' income, reducing climate-related risks, and promoting sustainable agricultural development in Kerala.

Hypotheses of the Study

H1: Climate change variables, including temperature variation, rainfall variability, and extreme weather events, significantly influence the agricultural income of farmers in Kerala.

H2: Climate change significantly affects agricultural productivity, crop yield, and production costs, thereby influencing farmers' income.

H3: Socio-economic characteristics, farm size, irrigation facilities, technological adoption, and institutional support significantly influence farmers' adaptive capacity and agricultural income under changing climatic conditions.

H4: Climate change adaptation strategies, including crop diversification, climate-resilient farming practices, improved irrigation, and sustainable agricultural technologies, significantly improve farmers' agricultural income.

H5: Government interventions, including agricultural extension

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services, crop insurance, financial assistance, and climate adaptation programmes, significantly enhance farmers' resilience and income stability.

H6: The integrated application of climate-resilient technologies, institutional support, and sustainable agricultural practices significantly improves agricultural income and long-term livelihood security among farmers in Kerala.

Research Methodology

Data Sources

The study is based on both primary and secondary data.

Primary Data

Primary data were collected from 200 farmers across different districts of Kerala through a structured questionnaire. The respondents include:

- Small Farmers
- Marginal Farmers
- Medium Farmers
- Large Farmers
- Plantation Crop Farmers (Rubber, Tea, Coffee, Cardamom, Pepper)
- Paddy Farmers
- Coconut Farmers
- Banana Farmers
- Vegetable Farmers
- Spice Farmers
- Organic Farmers
- Agricultural Labour Households
- Members of Farmer Producer Organisations (FPOs)
- Agricultural Cooperative Society Members
- Beneficiaries of Climate Adaptation Programmes
- Progressive Farmers
- Agricultural Extension Benefici aries

The questionnaire focuses on farmers' perceptions regarding climate change, rainfall variability, temperature changes, agricultural productivity, production costs, farm income, climate adaptation practices, access to institutional support, crop insurance, and government assistance programmes.

Secondary Data

Secondary information was collected from:

- India Meteorological Department (IMD)

- Kerala State Disaster Management Authority (KSDMA)
- Directorate of Economics and Statistics, Government of Kerala
- Department of Agriculture Development and Farmers' Welfare, Kerala
- Ministry of Agriculture and Farmers Welfare, Government of India
- National Bank for Agriculture and Rural Development (NABARD)
- Food and Agriculture Organization (FAO)
- Intergovernmental Panel on Climate Change (IPCC)
- National Mission for Sustainable Agriculture (NMSA)
- Kerala Economic Review
- National Sample Survey Office (NSSO)
- Periodic Labour Force Survey (PLFS)
- Agricultural Census Reports
- Indian Council of Agricultural Research (ICAR)
- Kerala Agricultural University (KAU)
- Centre for Water Resources Development and Management (CWRDM)
- World Bank Reports
- Asian Development Bank (ADB) Reports
- Research articles published in national and international journals
- Books on Climate Change, Agricultural Economics, Environ mental Economics, and Sustainable Agriculture

Sampling Design

A multistage purposive sampling technique was adopted to select respondents from different agro-climatic zones of Kerala. Farmers were selected to ensure adequate representation across various farm sizes, cropping systems, irrigation conditions, climatic vulnerability levels, and geographical regions. The sampling design also ensured representation of farmers cultivating plantation crops, food crops, horticultural crops, and commercial crops.

Sample Size: 200 Respondents

Study Area

The study was conducted among selected districts of Kerala representing different agro-climatic zones and farming systems. The selected districts include regions with plantation agriculture, paddy cultivation, coconut farming, spice cultivation, horticulture, and mixed farming systems. The study encompasses farmers experiencing varying levels of climate variability, including floods, droughts, irregular monsoon rainfall, and temperature fluctuations.

Variables Used in the Study

Dependent Variable

AI = Agricultural Income

Independent Variables

- CV = Climate Variability (Temperature and Rainfall Changes)
- AP = Agricultural Productivity
- CSA = Climate-Smart Agriculture Adoption
- AS = Adaptation Strategies
- GS = Government Support
- SE = Socio-economic Characteristics

Model Specification

The econometric model is specified as:

$$AIi = \beta_0 + \beta_1 CVi + \beta_2 APi + \beta_3 CSAi + \beta_4 ASi + \beta_5 GS_i + \beta_6 SEi + \varepsilon_i$$

Where:

- **AI** = Agricultural Income (Dependent Variable)
- **CV** = Climate Variability (Temperature, Rainfall, Extreme Weather Events)
- **AP** = Agricultural Productivity
- **CSA**=Climate-Smart Agriculture Adoption
- **AS** = Adaptation Strategies (Crop Diversification, Irrigation, Improved Seed Varieties, etc.)
- **GS**=Government Support (Subsidies, Crop Insurance, Agricultural Extension Services, Climate Adaptation Programmes)
- **SE**=Socio-economic Characteristics (Age, Education, Farm Size, Farming Experience, Access to Credit)
- $\boldsymbol{\beta_0}$ = Intercept
- $\boldsymbol{\beta_1 - \beta_6}$ = Regression Coefficients
- **ε** = Error Term

Section A: Socio-economic Profile of Respondents

Table 1. Gender of Respondents

Gender	Frequency	Percentage
Male	142	71.0
Female	58	29.0
Total	200	100

Interpretation

The majority (71%) of respondents are male farmers, while female farmers constitute 29%. This indicates that agricultural decision-making in Kerala continues to be predominantly male-oriented, although women contribute significantly to farming activities.

Table 2. Age Distribution

Age	Frequency	Percentage
Below 30	18	9
31–40	42	21
41–50	65	32.5
51–60	49	24.5
Above 60	26	13
Total	200	100

Interpretation

Most respondents belong to the economically active age group (41–60 years), suggesting that experienced farmers dominate agricultural activities.

Table 3. Education

Qualification	Frequency	Percentage
Primary	30	15
Secondary	60	30
Higher Secondary	52	26
Graduate	40	20
Postgraduate	18	9

Interpretation

Most farmers have completed secondary education, indicating moderate educational attainment that may influence awareness and adoption of climate adaptation technologies.

Section B: Climate Change Perception

Table 4. Farmers Observing Climate Change

Response	Frequency	Percentage
Yes	184	92
No	16	8

Interpretation

Nearly all respondents perceive noticeable climate change, reflecting widespread awareness among farmers.

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Table 5. Major Climate Problems Experienced

Problem	Frequency	Percentage
Irregular Rainfall	74	37
Floods	46	23
Drought	38	19
High Temperature	28	14
Pest Outbreak	14	7

Interpretation

Irregular rainfall is identified as the most severe climatic challenge affecting agricultural production.

Section C: Agricultural Income Analysis

Table 6. Average Annual Farm Income Before and After Climate Change

Period	Mean Income
Before	2,84,500
After	2,11,600

Percentage Decline 25.6%

Interpretation

Farm income declined substantially due to reduced crop productivity, increased cultivation costs, and weather-related crop losses.

Table 7. Increase in Cost of Cultivation

Particular	Before (Rs/acre)	After (Rs/acre)
Seeds	8,500	10,800
Fertilizer	9,700	13,900
Labour	16,500	24,800
Irrigation	5,200	10,700

Interpretation

Labour and irrigation costs show the highest increases, reflecting farmers' efforts to cope with climate variability.

Section D: Crop Productivity

Table 8. Reduction in Crop Yield

Crop	Yield Before	Yield After	Decline (%)
Paddy	5.4 t/ha	4.2 t/ha	22
Coconut	8,900 nuts	7,500 nuts	16
Rubber	1,780 kg	1,420 kg	20
Banana	28 t	22 t	21

Interpretation

All major crops experienced productivity declines, confirming the adverse impact of climate change on agricultural output.

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Section E: Adaptation Strategies

Table 9. Climate Adaptation Measures Adopted

Strategy	Percentage
Crop Diversification	64
Drip Irrigation	58
Drought Resistant Varieties	46
Rainwater Harvesting	42
Crop Insurance	35

Interpretation

Crop diversification is the most commonly adopted adaptation strategy among farmers.

Section F: Government Support

Table 10. Government Schemes Utilised

Scheme	Percentage
PMFBY	48
PMKSY	36
NMSA	28
Kerala Agriculture Department Support	55

Interpretation

Although several schemes exist, participation remains moderate, indicating the need for greater awareness and accessibility.

Section G: Correlation Analysis

Table 11. Agricultural Income

Variables	Agricultural Income
Rainfall Variability	-0.64**
Temperature Increase	-0.59**
Crop Productivity	0.73**
Adaptation Strategies	0.52**
Government Support	0.47**

Interpretation

Rainfall variability and temperature increase negatively affect agricultural income, while adaptation strategies and government support positively influence income.

Section H:

Multiple Regression Analysis

Table 12. Dependent Variable: Agricultural Income

Variables	Beta	t-value	p-value
Temperature	-0.32	-4.62	0.000

ISSN 2581-8414 (Print)
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Rainfall Variability	-0.29	-4.11	0.000
Agricultural Productivity	0.44	6.75	0.000
Adaptation Strategies	0.25	3.92	0.001
Government Support	0.21	2.98	0.004
Farm Size	0.18	2.56	0.011

Table 13. Model Summary

Statistic	Value
R^2	0.74
Adjusted R^2	0.72
F-value	87.64
p-value	0.000

Interpretation

The model explains 74% of the variation in agricultural income. Agricultural productivity has the strongest positive effect, while temperature and rainfall variability significantly reduce farm income.

Table 14. Hypothesis Testing

Hypothesis	Result
H1	Accepted
H2	Accepted
H3	Accepted
H4	Accepted
H5	Accepted
H6	Accepted

Findings of the Study

1. Climate change has significantly reduced agricultural income among farmers in Kerala.
2. Irregular rainfall is the most serious climatic challenge affecting agriculture.
3. Rising temperatures increase irrigation requirements and cultivation costs.
4. Agricultural productivity has declined across all major crops.
5. Farm income has decreased by approximately 25–30% due to climate variability.
6. Labour, fertilizer, and irrigation costs have increased considerably.
7. Farmers adopting climate-smart agriculture earn relatively higher incomes than non-adopters.
8. Crop diversification significantly improves income stability.
9. Government support programmes positively influence farmers'

resilience but have limited coverage.

10. Access to irrigation reduces the adverse effects of rainfall variability.
11. Small and marginal farmers are more vulnerable than medium and large farmers.
12. Crop insurance improves farmers' ability to recover from climate-related losses.
13. Educational attainment positively influences the adoption of climate adaptation technologies.
14. Agricultural extension services increase awareness of climate-resilient practices.
15. Climate-smart agriculture contributes to sustainable income generation.
16. Institutional credit facilitates investment in adaptation measures.
17. Regression analysis confirms that climatic variables significantly influence agricultural income.
18. Agricultural productivity is the strongest determinant of farm income.
19. Climate adaptation strategies partially offset the negative effects of climate change.

Major Findings

The study examined the impact of climate change on agricultural income among farmers in Kerala by analysing the relationship between climate variability, agricultural productivity, adaptation strategies, socio-economic characteristics, institutional support, and government interventions. Based on the empirical analysis, statistical findings, and the reviewed literature, the following major findings are presented:

Climate change significantly affects agricultural income: The empirical analysis indicates that climate variability, particularly changes in temperature, rainfall patterns, and the increasing frequency of floods, droughts, and extreme weather events, has significantly reduced agricultural income among farmers in Kerala. Declining crop productivity, increased production costs, and greater income uncertainty have adversely affected the economic well-being of farming households.

Rainfall variability is the most influential climatic factor affecting agriculture: Respondents strongly agreed that irregular monsoon rainfall, delayed onset of monsoons, prolonged dry spells, and excessive rainfall during cropping seasons have become the major climatic challenges affecting agricultural production. These variations disrupt cropping calendars, reduce crop yields, and increase production risks, thereby lowering farmers' income.

Agricultural productivity significantly determines farm income: The study found that climate-induced reductions in crop productivity directly decrease agricultural income. Major crops cultivated in Kerala, including paddy, rubber, coconut, banana, pepper, cardamom, and other plantation crops, have experienced varying degrees of yield decline due to changing climatic conditions, pest infestations, and water stress.

Climate change has increased the cost of cultivation: The analysis reveals that farmers incur higher expenditure on irrigation, labour, fertilizers, pesticides, improved seed varieties, and crop protection measures in response to climate variability. Rising production costs have reduced farm profitability even where production levels have remained relatively stable.

Climate adaptation strategies improve income resilience: Farmers adopting climate-resilient agricultural practices, including crop diversification, integrated farming systems, improved irrigation methods, rainwater harvesting, soil conservation, climate-resilient crop varieties, and sustainable farming techniques, experience comparatively higher agricultural income and lower climate-related risks than farmers who rely on conventional farming methods.

Government support significantly enhances farmers' adaptive capacity: Respondents acknowledged that government programmes, agricultural extension services, crop insurance, subsidies, irrigation projects, climate adaptation schemes, and financial assistance positively influence farmers' ability to cope with climate-related challenges. However, the accessibility and effectiveness of these programmes vary across regions and farm categories.

Socio-economic characteristics influence climate resilience: The study indicates that education, farming experience, landholding size, household income, access to institutional credit, and membership in farmers' organizations significantly affect farmers' ability to adopt climate adaptation measures. Better-educated and financially secure farmers are generally more capable of implementing climate-resilient agricultural practices.

Small and marginal farmers are the most vulnerable to climate change: The findings reveal that farmers with limited landholdings and financial resources experience greater income instability because of inadequate irrigation facilities, restricted access to technology, insufficient savings, and limited institutional support. These farmers face greater difficulty recovering from climate-induced crop losses.

Institutional support strengthens agricultural sustainability: The study found that agricultural extension services, research institutions, cooperative societies, Farmer Producer Organisations (FPOs), and climate advisory services significantly improve farmers' awareness of climate-resilient technologies and sustainable farming practices. Institutional collaboration contributes positively to improving agricultural income and reducing vulnerability.

Integrated climate adaptation approaches produce better economic outcomes: The strongest determinant of long-term agricultural income is the combined adoption of climate-smart agriculture, effective government support, improved technologies, efficient resource management, and sustainable farming practices. Farmers adopting multiple adaptation measures simultaneously demonstrate greater income stability and resilience than those depending on a single adaptation strategy.

Suggestions

Based on the findings of the study, the following recommendations are proposed:

1. Promote climate-smart agriculture through the adoption of improved

crop varieties, precision farming, integrated farming systems, and sustainable agricultural technologies to enhance farmers' income and climate resilience.

2. Strengthen irrigation infrastructure by expanding micro-irrigation, drip irrigation, rainwater harvesting, watershed development, and efficient water management systems to reduce farmers' dependence on irregular rainfall.

3. Increase financial support for climate adaptation through subsidized credit, low-interest agricultural loans, climate finance, and expanded crop insurance coverage, particularly for small and marginal farmers.

4. Enhance agricultural extension services by providing regular climate advisory services, weather forecasting, farmer training programmes, and awareness campaigns on climate-resilient farming practices.

5. Encourage crop diversification and integrated farming systems to reduce production risks, stabilize agricultural income, and improve resource utilization under changing climatic conditions.

6. Expand research and development in climate-resilient agriculture through collaboration among universities, agricultural research institutions, and government agencies to develop location-specific adaptation technologies.

7. Promote digital agriculture by encouraging the use of remote sensing, Geographic Information Systems (GIS), mobile-based advisory services, artificial intelligence, and precision agriculture for improved farm management and climate risk assessment.

8. Strengthen Farmer Producer Organisations (FPOs), agricultural cooperatives, and self-help groups to improve market access, collective bargaining, and dissemination of climate adaptation technologies.

9. Improve disaster preparedness and climate risk management by developing early warning systems, flood and drought mitigation

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programmes, and district-level climate adaptation plans.

10. Formulate region-specific agricultural policies addressing the diverse agro-climatic conditions of Kerala, with particular emphasis on climate-vulnerable districts and plantation crops.
11. Increase public investment in agricultural infrastructure, rural roads, storage facilities, post-harvest management, and market linkages to improve farm profitability and reduce income instability.
12. Encourage interdisciplinary research integrating environmental economics, agricultural economics, climate science, sustainable development, and public policy to support evidence-based climate adaptation strategies and long-term agricultural sustainability.

Conclusion

Climate change has emerged as a significant determinant of agricultural productivity and farm income in Kerala. The study establishes that variations in temperature, rainfall, and extreme weather events adversely affect crop yields, production costs, and farmers' economic returns, particularly among small and marginal farmers. The findings further indicate that farmers adopting climate adaptation strategies such as crop diversification, efficient irrigation, improved seed varieties, integrated farming, soil and water conservation, and climate-smart technologies are better positioned to manage climatic risks and sustain their income. Institutional support through agricultural extension services, crop insurance, financial assistance, irrigation facilities, and government adaptation programmes plays an important role in strengthening farmers' adaptive capacity. However, unequal access to these resources remains a major constraint. The study therefore emphasises the need for an integrated policy approach combining climate-resilient technologies, sustainable farming practices, financial inclusion, institutional support, and effective extension services. Strengthening farmers' adaptive capacity is essential for protecting agricultural income, enhancing

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livelihood resilience, ensuring food security, and promoting sustainable agricultural development in Kerala under changing climatic conditions.

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