Adaptation to Climate Change and Technical Efficiency in Paddy Farming: A Case Study in Wayanad and Palakkad Districts, Kerala

Dr. Basheer K K[1*], & Prof. G Sridevi[2]

[1*]Assistant Professor Economics, Dept. of Economics. NMSM Govt College Kalpetta, Wayanad-673122, Email: basheerkkw@gmail.com, 9544589680,
2Professor, School of Economics, University of Hyderabad, Gachebowly-500046, Email: gummadi645@gmail.com.

***Corresponding Author:** Dr. Basheer K K
*Email: basheerkkw@gmail.com.

Abstract

The Intergovernmental Panel on Climate Change has consistently recognized the anthropogenic nature of climate change and its impact on global systems, particularly agriculture. Recognizing the vulnerability of the agricultural sector, organizations like the Food and Agriculture Organization and the United Nations Framework Convention on Climate Change have emphasized the urgent need for sustainable agricultural practices to mitigate the adverse effects of climate change. This study investigates the link between farmers' adaptive capacity, technical efficiency, and overall agricultural sustainability. Using stochastic frontier analysis, the research examines data from 330 paddy farmers in Wayanad and Palakkad, two climate-vulnerable districts in Kerala, India. The findings reveal a strong positive correlation between climate adaptation practices, coping strategies, and the technical efficiency of paddy farming. However, the study also highlights that a lack of comprehensive coping strategies can hinder farmers' ability to effectively address climate change impacts. This underscores the crucial need to integrate both climate adaptation practices and coping strategies into farm-level planning to enhance the long-term sustainability of agriculture in the face of a changing climate

Keywords: Climate Change, technical efficiency, stochastic frontier analysis, adaptation strategies, coping strategies.
JEL: Q15, Q12, Q13 Q01.
UDC: 574.5(541.1+541.2)

Introduction

The concept of sustainable development has its route from the 12th century B.C. in connection with forest management (Ehnert, 2009). However, the term gained momentum and was used in a contemporary sense only during the 1970s with the Neo-Malthusian Club of Rome's work on a development called Limits to Growth, led by Meadows et al. (Grober 2007). The term gained even wider currency among the public after publishing two reports: the World Conservation Strategy in 1980 by the International Union for Conservation of Nature and the Brundtland report titled Our Common Future by the World Commission on Environment and Development (Leal 2015). Later, the Intergovernmental Panel on Climate Change unequivocally states in its major assessment reports since 1990 that ongoing climate change is real and anthropogenic (IPCC AR6, 2022). There have been observable changes in global average earth and ocean temperatures, as well as uncertain variability in regional rainfall patterns, shifting ecological zones, and rising sea levels and melting of polar ice caps, in addition to extreme climatic conditions such as drought and flooding in various parts of the world (Philander, 2008). Every sector of the economy will be adversely affected by the ongoing climate change; however, being a climate depended and sensitive sector, agriculture is arguably one of the most damaged sectors due to climate change and hence will be more vulnerable (Philander, 2008).

The UNFCCC (2020) and FAO (2021) have stressed the importance of sustainability in the agriculture sector, stating that it can help mitigate the negative impacts of climate change by enabling the sector to adapt and cope. The concept of sustainable development was popularised by the Brundtland Commission, leading to a surge in the literature on sustainability across many fields of study (Cordonier et al., 2004). However, there is a lack of consensus among scholars on what constitutes sustainable agriculture, making it one of the areas of research where different scholars have proposed various definitions of sustainability at different times.

Conway (1985) argues that sustainability is the ability of a system to retain productivity in the face of a substantial disturbance, such as is caused by intensive stress or a huge perturbation. Agriculture sustainability has been classified into several categories, including sustainability as an ideology, a set of strategies, the ability to achieve a wide set of goals, and the potential to continue into the future (Hanson, 1996). Monteith (1990) defines a farming system is sustainable over a defined period if outputs do not decrease when inputs are not increased. While directly applying Brundtland's definition, Gray (1991) states that agriculture sustainability is the maintenance of the net benefits agriculture provides to society for present and future generations. Pretty (2008) interprets sustainability as the development of the technologies and practices that do not have an adverse effect on the farming environment, accessible and effective for farmers, [and] maintain agricultural productivity over a long period.

Many empirical studies on agricultural sustainability have adopted either Conway's (1985) or Pretty's (2008) definition of sustainability and focused on productivity or efficiency analyses. However, in the context of climate change, it could be argued that maintaining long-term productivity despite disturbances and adopting adjustment practices, including short- and long-term coping and adaptation strategies, is necessary for a sustainable agriculture system. Yet, few empirical studies have examined the combined impact of these two aspects, namely long-term productivity improvement and climate-induced risk management through adaptation and coping strategies. Therefore, the present study aims to investigate how climate change adaptation practices and coping mechanisms affect agricultural technical efficiency.

The remaining parts of the paper have been organized in the following ways. The next section presents the theoretical framework, which addresses the significant issues drawn from the literature, the analytical framework employed in the study, and the data sources and materials used. In the fourth section, the study analyses the perception of paddy farmers regarding climate change, the adaptation strategies and coping mechanisms employed in the study area, and how these factors impact the efficiency of paddy farming. Finally, the last section summarises the study's findings and policy implications.

Theoretical structure

Studies that evaluate the performance of the agriculture sector use one of two methods. The first method involves examining the Total Factor Productivity (TFP) growth of the agriculture sector, which then decomposes the sources of input growth in total output growth. Several studies have used TFP indexes to understand the nature of agriculture growth and productivity in India, including Mohan (1974), Rosegrant et al. (1992, 1995), Dholakia et al. (1993), Kumar et al. (1994), Desai et al. (1997), Evenson et al. (1998), Fan et al. (1999), Janaiah et al. (2005), Joshi et al. (2006), Chand et al. (2012), and Birthal et al. (2014). However, some studies have used the TFP approach to understand agricultural sustainability, such as Ninan et al. (1993), Kumar et al. (1998), Rosegrant et al. (2000), Kumar (2006), Bhatia (2006), and Prashanth et al. (2014). Studies on Kerala agriculture by Srinivas et al. (2009), Aswathy et al. (2013), and Karunakaran (2014) have also used TFP indexes to deal with agriculture productivity. However, these studies may overestimate agricultural productivity as they do not decompose the improvement in efficiency, which also contributes to agricultural productivity.

The second method used in productivity studies separates output growth into technological change, technical efficiency changes, and input growth. Many studies, such as those by Kalirajan et al. (1981, 2006), Huang et al. (1984), Ray (1985), Fan et al. (1991), Chaudhary (2012), Shanmugam et al. (2006), Makki et al. (2012), Auci et al. (2014), and Pradhan et al. (2018), have used stochastic frontier analysis (SFA) to incorporate technical efficiency components into their productivity studies. These studies assume that greater responsiveness of technical efficiency to output components indicates a shift toward sustainability. However, these groups of studies fail to consider specific adaptation practices and coping strategies related to climate change, even though they can influence production efficiency.

In context to foreign countries, some studies have utilized stochastic frontier analysis to analyze the impact of climate change adaptation strategies on agricultural technical efficiency, including Otitoju et al. (2014), Roco et al. (2017), Shimada et al. (2019), Owoeye (2020), and Adzawla et al. (2021). In Tamil Nadu agriculture in India, Vijayasarathy et al. (2015) utilized SFA to investigate the effects of climate conditions on technical efficiency and the implications of climate change adaptation. Meanwhile, Kumar et al. (2019) used Data Envelopment Analysis to assess the input-use efficiency of climate-resilient technology adaptors in paddy and wheat crops in Punjab agriculture. However, no studies in Kerala agriculture have used SFA to examine the effects of adaptation practices and coping strategies on technical efficiency. Therefore, this study aims to investigate the impact of adaptation practices and coping strategies on the technical efficiency of paddy cultivation in Kerala using a stochastic frontier production function approach.

Materials and Methods

The concept of efficiency is commonly used to analyze the performance of a production unit.[1] Paddy farming is technically efficient as a production unit if it can produce the highest possible output from a given set of inputs. The concept of technical efficiency is used in the study to analyze the performance of paddy cultivation in the context of climate change. The use of this concept in the present study has the following advantages. The study assumes that paddy farmers using various coping strategies and adaptation practices will be more efficient. Therefore, there are policy implications for improving efficiencies in such analyses by considering better climate change adaptation options. In other words, appropriate adaptation practices that contribute to improvement in the efficiency of paddy cultivation can be identified.

---

[1] Efficiency can be of two types, 1 - Allocative efficiency: Allocative Efficiency is defined as the ability and willingness to use the quantity of inputs that will maximise net revenue(profit), given the current conditions of factor supply and market demand (Kalirajan et al., 1999). 2- Technical efficiency: It is defined as the ability and willingness of farms to produce the maximum possible output with specified quantity of inputs, given the prevailing technology and environmental conditions. In other words, a farm is said to be technically efficient, if it able to realise the full potential of its technology with a given set of inputs. The technical efficiency can be further subdivided into input oriented and output oriented technical efficiency. Output oriented technical efficiency is the ability of a production units to produce the maximum possible output from given sets of inputs and technical conditions. Input oriented technical efficiency means ability of the production units to produce a given level of output from the lowest possible input costs.

There are two approaches, non-parametric and parametric, for measuring the efficiency of the production unit. Firstly, the non-parametric model estimation technique called the Data Envelopment Analysis (DEA) uses only input and output data. It is deterministic because inefficiencies are attributed to any deviation from the maximum possible output. Second, "Stochastic Frontier Analysis (SFA) is a parametric approach for estimating the coefficients of independent input variables in the production function. Furthermore, Stochastic Frontier Analysis considers random error arising from typical stochastic and natural inefficiencies. The present study uses stochastic frontier production specifications to fit the study's objectives best.

Stochastic Frontier Analysis

Stochastic Frontier Analysis is used in the present study to assess the performances of farm production systems at the micro-level. The stochastic production frontier models were simultaneously introduced by Aigner, Lovell, Schmidt (1977) and Meeusen Van den Broeck (1977).

The production function can be specified in the equation (Batese & Coelli 1992)… (1).

$$Y_i = \beta_0 + \beta X_i + \varepsilon_i \text{……………………..(1)}$$

Here,

Y_i is the log of paddy output, β_0 and β_i are parameters.

X_i is the $Zx1$ vector of input quantities, and β is the $Zx1$ vector of parameters to be estimated. ε_i is a composite error term, $-u_i$ is the technical inefficiency error, and v_i is the usual statistical random error or noise. $\varepsilon_i = -u_i + v_i$ is assumed to be independently and identically distributed $N\ (0, \sigma_v^2)$ and independent of u_i, while u_i are non-negative random variables, assumed to be independently and identically distributed as truncated normal; $u_i \sim iidN^{+}(0, \sigma_0^2)$.

The equation (1) can be alternatively written as

$$Y_i = f(X_i\,; \beta) exp\ (u_i - v_i) \text{……………………………. (2)}$$

Herer $f(.)$ can assume different functional forms such as Cobb-Douglas and translog functional forms. In the present study, the production function assumes the Cobb-Douglas type since the elasticity of substitution is estimated at a constant level. From equation (2), the technical efficiency of the paddy farmers can be defined as

$$T.E._i = \frac{Y_i}{Y_{i*}} = \frac{f(X_i\,; \beta) exp\ (v_i - u_i)}{f(X_i\,; \beta) exp\ v_i} \text{ ………………… (3)}$$

The numerator in equation (3) is the actual observed output, and the denominator is the potential frontier output determined by the best production practices. Therefore

$$T.E._i = exp\ (u_i) \text{ ………………… (4)}$$

Following the estimation of technical efficiency scores for individual paddy farmers, the next steps are to understand the effects of the farmers' socioeconomic characteristics, coping strategies, and adaptation practices on technical efficiency". The technical inefficiency model can be specified in (5)

$$U_i = \delta_0 + \sum_{n=1}^{k} \delta_i Z_j \text{ …………………………. (5)}$$

Where U_i denotes the inefficiency effects. δ_i denotes coefficients of climate change adaptation practices, coping strategies and socioeconomic factors while Z_j is the vector of factors influencing technical inefficiencies. The Maximum Likelihood method developed by Battese and Coelli (1995) is used to obtain estimates for the stochastic frontier and the inefficiency model in a single step.

Empirical Model

The estimation of output, input variables, and coefficients can be specified empirically

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 \text{……..(6)}$$

Y = Total quantity of Paddy output(kg), explanatory variables X_1 **to** X_6 measure inputs such as the area under paddy cultivation (acres), human labour in man-days, seeds(kg), organic manure(kg) and chemical fertilizer (kg), pesticides (litres), and $\beta_1\ to\ \beta_6$ measures their respective parameters.

An empirical model for the effects of farm-specific socioeconomic features, adaptation practices, and coping strategies on technical efficiency/inefficiency can be given as in (7).

$$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 \text{………(7)}$$

Where $\boldsymbol{\delta_1}$ to $\boldsymbol{\delta_4}$ Indicate farm-specific socioeconomic factors that affect efficiencies, such as the farmer's years of education, farm household size, farmer age, and year of farm experience. The research suggests that education has a negative correlation with technical inefficiencies, meaning that farmers with more years of education tend to have lower levels of inefficiency. This is likely because education provides farmers with access to up-to-date information and knowledge on how to cope with and adapt to changing climates, leading to more efficient farming practices. As a result, promoting education among farmers could be an effective strategy for improving the efficiency of agricultural production in the context of climate change.

The projected association between farm family size and farm inefficiency is positive because more household members engaged in farming increases routinized and hard menial labour, which lowers farm efficiency. The more household members engaged in farming, the more tasks and responsibilities are distributed among them, leading to inefficiencies due to a lack of specialization and coordination. In addition, larger farm families may face constraints in accessing resources such as land and capital, which can also affect their efficiency. The more experience a farmer has, the more knowledge and skills they acquire, leading to a lower level of technical inefficiency. As a result, the relationship between farmer experience and technical inefficiency is expected to be negative, meaning that more experienced farmers will likely be more efficient in their agricultural production.

As farmer ages, they become less capable of carrying out everyday agricultural tasks; consequently, technical inefficiency is projected to have a positive association. It is true that as farmers age, they may experience declines in physical and cognitive abilities, which could lead to decreased efficiency in carrying out agricultural tasks. Therefore, the relationship between farmer age and technical inefficiency is often expected to be positive. However, it is important to note that this relationship may vary depending on the specific context and circumstances of the farmers being studied. Other factors, such as access to labour-saving technologies and support systems, may also play a role in determining the relationship between farmer age and technical efficiency.

Farmers' adaptation and coping strategies to climate variability are included in the model as factors influencing paddy cultivation's technical efficiency. A farmer may employ single or several practices to adapt to climate change. As a result, they are complementary rather than substitutable. Therefore, in the present study, parameters $\boldsymbol{\delta_5}$ to $\boldsymbol{\delta_6}$ demonstrate complementary coping strategies and complementary adaptation practices, respectively. Paddy farmers employ various coping measures, including delayed sowing, summer ploughing, change between direct sowing and transplanting, additional irrigation facilities, drought-tolerant/resistant seed varieties, drip irrigation, continuous cropping, and crop insurance. Because adaptation and coping strategies are complementary, more and more farmer-joined practices help farmers cope and adapt to climate variability. The relationship between mean adaptation and coping strategy scores and technical inefficiency is expected to be negative. It is because adaptation and coping strategies help farmers to mitigate the negative impacts of climate change and improve their production efficiency. By implementing effective adaptation and coping strategies, farmers are better equipped to deal with changing weather patterns and can reduce the risk of crop failure or low yields. As a result, technical inefficiencies are likely to be lower among farmers with higher mean scores for adaptation and coping strategies.

Mixed farming, changing cropping patterns to grow less water-intensive crops, building farm ponds, increasing non-farm employment, increasing the number of livestock, particularly milch animals and goats, installing new borewells, shifting from crops to tree crops, migration, lift irrigation, and changing cropping patterns are all adaptation measures used by paddy farmers in response to climate change". The expected relationship between complementary adaptation strategies and technical inefficiency is negative as more and more adaptation practices in combination employed by paddy farmers are likely to reduce their technical inefficiencies. The variance of random errors, σ_v^2, and that of technical inefficiency effects σ_u^2 and the overall variances $\sigma^2 = \sigma_u^2 + \sigma_v^2$ of the model are related. The ratio $\gamma = \sigma_u^2/\sigma_v^2$ is called Gama, which measures the total variation of output from the frontier that can be attributed to technical inefficiency.

Study Area, Data Collection and Sampling

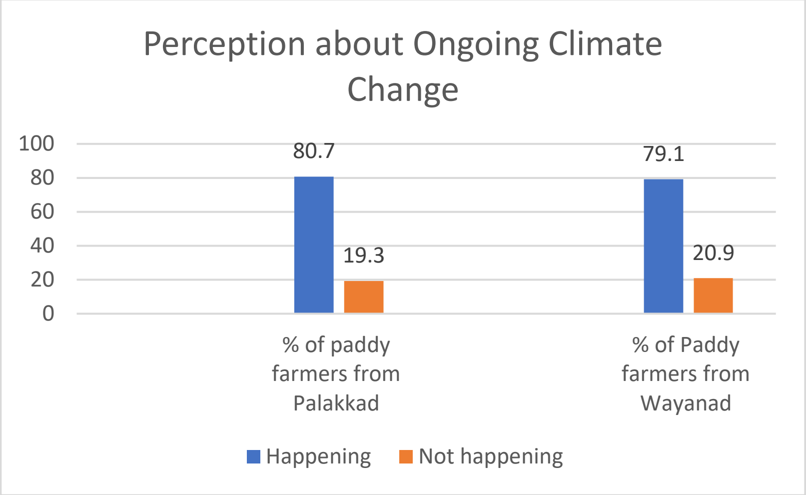
The primary study is carried out for the Wayanad and Palakkad districts of Kerala. Wayanad district is hilly and has a fragmented landholding pattern, which makes it vulnerable to soil erosion, landslides and other climate change impacts. On the other hand, Palakkad has a semi-arid climate, making it susceptible to drought and other climate-related hazards. The district also has many small and marginal farmers who lack the resources to adopt climate-resilient farming practices. Therefore, conducting the study in these two districts is crucial to understanding the effects of climate change on agriculture and the role of adaptation practices and coping strategies in improving technical efficiency.

Furthermore, Wayanad and Palakkad are among Kerala's four major climate change hotspot districts (KSACC 2014). The resilience of farmers to climate change in these two districts is dismal due to several socioeconomic and geographical factors. For instance, Wayanad is one of the poorest districts declared by the ministry of minority affairs because of its socioeconomic backwardness. The district has the largest tribal population of 18% of the total Kerala state S.T. population (Census 2011). The socioeconomic backwardness of the district makes it least able to adapt to climate change. On the other hand, Palakkad has the largest production and area under paddy cultivation among the 14 districts of Kerala (Economic Review, 2018). Palakkad has a higher concentration of scheduled caste population to the total district population, with livelihood derived primarily from high climate-sensitive agriculture and allied activities.

The field survey was conducted in September, October, and November 2019 and collected primary data from 330 paddy farmers in Palakkad and Wayanad districts. Multi-stage random sampling techniques were employed to select the samples in the study. In the first stage, Wayanad and Palakkad are the two most vulnerable districts in Kerala (KSACC, 2008) to climate change is selected. In the second stage, three blocks, one from Wayanad and two from Palakkad, are identified according to the largest area under paddy cultivation. Accordingly, Panamaram Community Development Block(CDB) from Wayanad district and Kuzhalmannam and Alathur CDB of Palakkad district are selected. In the third stage, from all 15-gram panchayats of Kuzhalmannam and Alathur Block of Palakkad study area, 12 to 13 samples per gram panchayats make up a total of 192 random samples were collected. For the Wayanad study area, from all 5-gram panchayaths of Panamaram Block, 28 to 27 samples per gram panchayats ---making a total of 138 samples, were collected. A structured questionnaire is used for data collection, and data pertain to socioeconomic characteristics, various inputs costs incurred and outputs of paddy cultivations, formal and informal sources of credit to farmers, farmers' perception to climate change, and finally, adaptation and coping strategies employed in the farming, among others were included in the questionnaire.

Farmers' Perceptions of the Climate Change

This study undertakes an examination of paddy farmers' perceptions of climate change at various levels before dealing into an analysis of the technical efficiency of their agricultural practices. The research employs a set of variables, including years of climate change awareness, agreement or disagreement regarding the existence of ongoing climate change, perceptions of changes in average rainfall and temperature, and the ranking of various climate change factors. In response to the query about their agreement with the existence of ongoing climate change, a substantial majority of farmers expressed agreement. In Wayanad, 110 out of 138 farmers (constituting approximately 80% of respondents) agreed with the notion of ongoing climate change, while in the Palakkad district, 152 out of 192 farmers did likewise. When asked to describe climate-change-related incidents, respondents frequently cited occurrences such as floods, droughts, heavy rains, fluctuations in rainfall patterns, and instances of weed or wildlife infestations. Notably, a few respondents exhibited misconceptions, exemplified by their references to ozone layer depletion and, curiously, its association with apocalyptic scenarios. This study sheds light on the multifaceted perceptions of climate change among paddy farmers and their potential implications for farm-level decision-making and technical efficiency.



Source: Primary Data, April, May 2021

Table:1, Perception about Climate Change Anomaly

Palakkad				Wayanad			
Temperature		Rainfall		Temperature		Rainfall	
Increasing	182(95)	Increasing	96(50)	Increasing	117(85)	Increasing	70(51)
Decreasing	3(1.5)	Decreasing	47(24)	Decreasing	6(4)	Decreasing	32(23)
Stable	5(2.5)	Stable	21(10)	Stable	11(8)	Stable	16(12)
Irregular	2(1.0)	Irregular	28(16)	Irregular	4(3)	Irregular	20(14)
Total	192	Total	192	Total	138	Total	138

Source: Primary Data, April, May 2021, Note, values in brackets are percentage.

In our attempt to understant farmers' perspectives on climate change, this study also employed a two-pronged approach, focusing on two pivotal climate change factors: temperature and rainfall. Farmers were queried regarding their perceptions of deviations in these factors from the long-term average. Specifically, in the context of temperature, we sought to discern farmers' perceptions of changes in long-term average temperatures in comparison to current levels. Their responses were categorized into options such as 'increasing,' 'decreasing,' 'stable/regular,' or 'irregular', were given in below table 1. It was found that a consensus emerged, with 95% of Palakkad farmers and 85% of Wayanad farmers perceiving an upward shift in temperature beyond long-term averages. On the contrary, perceptions of temperature decrease, stable, or irregularity were markedly rare in both research regions.

The perceptions regarding ongoing rainfall patterns displayed greater diversity. In Palakkad, 50% of farmers observed an increasing trend in present rainfall compared to long-term averages, while 24% perceived a decreasing pattern. A minority, constituting 10%, considered rainfall patterns to be consistent with historical norms, while 16% identified irregular deviations. In Wayanad, a comparable pattern unfolded, with 51% of farmers noting an increase in current rainfall relative to the long-term average, and 23% observing a decline. Approximately 12% reported stable rainfall patterns, while 14% identified irregular variations. These findings illuminate the intricate and multifaceted nature of farmers' climate change perceptions, offering valuable insights into their perspectives on temperature and rainfall dynamics in these regions.

Garrett ranking techniques are used in the present study to determine the dominant climate change factor perceived by paddy farmers. Farmers were asked to rank several alternatives regarding climate change factors to determine which climate change factors dominate farmers' perceptions. Farmers, for example, were asked to rank the following climate change factors in order of importance.

1. Temperature changes
2. Excess rain
3. Incidents of droughts
4. Incidence of flood
5. Decline in rainfall
6. Delay in rainfall
7. Growing season changes
8. Extreme weather events
9. Forest fire
10. Landslide

In the Garret ranking technique, the paddy farmers' rankings are first converted into score values with the following formula.

Percent position = 100(R_{ij}-0.5)/N_j,

Where, R_{ij}= Rank given for the i^{th} factor by the j^{th} respondent. N_j= No of factors ranked by the j^{th} respondent.

After listing the frequency of the factor ranking, the per cent position is converted into scores by referring to the Garret table. The scores of each individual are then added for each factor, yielding average scores. The selection of important climate change factors according to Garrett ranking method is given in table 2. A higher average temperature is the dominant climate change incident in farmers' perception. Drought and excess rainfall are two other major climate events that influence paddy farmers' views on climate change in the Wayanad and Palakkad study areas. Flood incidents, a decrease and delay in rainfall, and a change in the growing season are the other important climate change factors viewed by paddy farmers in the study area.

Table 2, Dominant Factors in Climate Change Perception

Climate Change Factors	Garret Mean Score	Rank	Climate Change Factors	Garret Mean Score	Rank
Palakkad			**Wayanad**		
Higher average Temperature	62.9	1	Incidents of droughts	58.4	1
Excess Rain	59.1	2	Higher average Temperature	55.1	2
Incidents of droughts	58.6	3	Excess Rain	54.6	3
Incidence of Flood	53.7	4	Incidence of Flood	54.0	4
Decline in Rainfall	51.3	5	Decline in Rainfall	50.0	5
Delay in rainfall	50.9	6	Growing Season Changes	42.6	6
Growing Season Changes	42.7	7	Extreme Weather events	41.3	7
Extreme Weather events	42.6	8	Delay in Rainfall	26.0	8
Forest Fire	21.9	9	Forest Fire	10.0	9
Land Slide	20.01	10	Land Slide	0.02	10

Source: Primary Data, April, May 2021

Adaptation Practices and Coping Strategies

Adapting to climate change refers to adjusting to actual or anticipated climatic stimuli to reduce risk and taking advantage of opportunities that arise from such actions, with a long-term goal in mind. On the other hand, coping strategies reduce risks due to climatic variability, primarily with a short-term goal. There is literature regarding foreign countries that attempts to evaluate the effects of agricultural adaptation practices on the efficiency of agriculture. Most research combines adaptation and coping strategies, with no distinction between adaptation practices and coping strategies. The present study attempted to distinguish between adaptation practices and coping strategies before examining their individual effects on the efficiency of paddy cultivation in the study area.

Table 3 describe the commonly used adaptation and coping strategies by the paddy farmers in the Wayanad and Palakkad study area. It has been found in the Wayanad study area that making delays in sowing is the most commonly used coping strategy. Many paddy farmers adopted the delay in sowing because of the late arrival of the monsoon. About half of the farmers in a Wayanad study area adopted direct sowing, crop insurance, and shifting from long to short maturing verities. Whereas in the Palakkad study area, more than 90 % of farmers adopt summer plaguing, transplanting, and continuous cropping. The same percentage of paddy farmers from Wayanad and Palakkad adopted interchange between short and long duration varieties and increased irrigation facilities as a coping strategy to climate variability. The drip irrigation method is the least adopted coping strategy in the study area.

Table:3, Coping and Apaptation Strategies by Paddy Farmers

Coping strategies

	Wayanad		Palakkad	
	No of farmers	Percentage	No of farmers	Percentage
Adoption of drought-tolerant verities	64	46.4	99	50
Application of drip irrigation method	14	10.1	0	0
Summer Ploughing	69	50	191	96.5
Direct Sowing	83	60.1	82	41.4
Transplanting	25	18.1	186	93.9
Continuous Cropping	43	31.2	187	94.4
Crop Insurance	70	50.7	148	74.7
Shifting to short-duration varieties	70	50.7	97	49
Increased irrigation facilities.	48	34.8	69	34.8
Delayed sowing	96	69.6	105	53

Adaptation Strategies

	Wayanad		Palakkad	
	No of farmers	Percentage	No of farmers	Percentage
Change in Cropping Pattern	84	43.8	127	66.1
Application of lift irrigation method	43	22.4	56	29.2
Mixed farming	79	41.1	51	26.6
Shifting to less water-intensive crops.	59	30.7	69	35.9
Construction of farm ponds	22	11.5	36	18.8
Livelihood diversification to non-farm employment	54	28.1	147	76.6
Increase in the number of livestock	67	34.9	46	24
Installation of new bore wells and wells	13	6.8	48	25
Shifting from crops to trees crops	73	38	30	15.6
Migration	13	6.8	50	2.6

Source: Primary Data, April, May 2021

Change in the cropping pattern and livelihood diversification through increased non-farm employment are the most commonly used adaptation practices in the Palakkad study area. A smaller number of paddy farmers in Palakkad are building farm ponds and switching from crops to tree crops. Changes in cropping pattern, mixed cropping, switching from the crop to tree crops are important adaptation practices in the Wayanad study area. In the Wayanad study region, a smaller number of paddy farmers practise the construction of farm ponds, wells, and borewells. Migration is the least adopted adaptation practice in Wayanad and Palakkad study areas.

Complementary Adaptation Practices and Coping Strategies by Paddy Farmers

In the context of climate change and variability, farmers need to adapt and cope with many strategies and practices. Since adaptation practices and coping strategies are not substitutable, complementary in adaptation practices and coping strategies is likely to increase the efficiency of paddy production (Basheer et al., 2021). Complementarity in practices and strategies means the ability of the farmers to undertake more than one strategy and practice to adjust to climate change and variability. Therefore, the present study analyses complementary adaptation and coping strategies in the sample study area. Table 4 discuss complementary adaptation and coping strategies in the sample study area.

Table: 4, Complimentary Adaptation Practices & Coping Strategies

Frequency of Adaptation Practices /Coping Strategies Used	**Complementary Adaptation Practices**				**Complementary Coping Strategies**			
	No of farmers in Palakkad	%	No of farmers in Wayanad	%	No of farmers in Palakkad	%	No of farmers in Wayanad	%
10	0	0	0	0	0	0	0	0
9	0	0	1	0.7	5	3.6	5	2.6
8	0	0	7	5.1	16	11.6	31	16.1
7	6	3.1	18	13	23	16.7	39	20.3
6	12	6.3	27	19.6	35	25.4	43	22.4
5	20	10.4	32	23.2	34	24.6	49	25.5
4	34	17.7	33	23.9	14	10.1	21	10.9
3	59	30.7	13	9.4	10	7.2	3	1.6
2	34	17.7	7	5.1	1	0.7	1	0.5
1	19	9.9	0	0	0	0	0	0
0	8	4.2	0	0	0	0	0	0

Source: Primary Data, April, May 2021. Note: Adaptation number indicate frequency of the adaptation or coping strategies

In the case of complementary adaptation practices in the Palakkad study area, 4.2 % of paddy farmers in the sample adopt no adaptation practices, whereas only 3.1 % of farmers adopt at least seven different adaptation practices in their farms. There are 30 % of paddy farmers in Palakkad who adopt at least three different adaptation practices at their farms. More than 60 % of farmers adopted at least 3 to 6 adaptation practices in the Palakkad study area. “Complementary adaptation practices in Wayanad show that most farmers adopted 3 to 7 adaptation practices. There are only seven farmers who adopted maximum of 8 different adaptation practices in Wayanad and seven farmers adopted minimum of 2 adaptation practices in the Wayanad study area. None of the Palakkad study region farmers used all of the complementary coping strategies. In the Palakkad research area, only one farmer used two coping methods, and only five farmers used a maximum of nine coping strategies. Majority of the farmers adopted at least 3 to 8 coping strategies in the Palakkad study area. Complementary coping strategies in Wayanad reveal that no farmer has ever used all of the coping strategies on their farm simultaneously. Only one farmer in Wayanad used a minimum of two coping strategies. Similar to the Palakkad study area, only five farmers used nine coping techniques in the Wayanad study area. In the Wayanad sample study area, the majority of the farmers used 4 to 8 coping techniques.

Impacts of Adaptation Practices and Coping Strategies on Climate Change

The Cobb-Douglas stochastic frontier model with inefficiency effect is used in the present study to investigate the impact of climate change adaptation and coping methods on the technical efficiency of paddy farming. Maximum Likelihood Estimate of (MLE) for the parameters are given in table 6 and 7. In both Wayanad and Palakkad study areas, farm size has a highly significant influence on the output of paddy cultivation. In the Wayanad sample study region, estimated parameters significantly impact paddy production, except for machine labour and plant protection. Except for labour in man-days, seeds, manure, machine labour, and plant protection have all demonstrated positive effects on paddy productivity in the Palakkad research area, though not statistically significant at the one per cent level. Return to scale is estimated to be less than one, indicating that paddy cultivation in both sampled research areas has a diminishing return to scale.

The efficiency model shows inefficiency effects exist because $\gamma = 1$ in the case of Wayanad study area and $\gamma > 0$. (γ is called gamma ratio explain variation in frontier output on account of farm-specific factors and adaptation practices and coping strategies adopted by the paddy farmers, if technical inefficiency is present in the model, γ ration will be lies between greater than zero and less than one).

The efficiency model shows that inefficiency exists in the model because $\gamma = 1$ in the case Wayanad study area and $\gamma > 0$ in the case of the Palakkad study area. The estimated coefficients for education, age, and adaption practises in Wayanad are negative and significant. When paddy farmers are receiving more and more years of education, they can better manage farm operations and increase awareness of improved input quality, which reduces inefficiencies. In Wayanad, the estimated parameters for age are negative and significant, meaning that as farmers get older, their abilities in performing various farm operations improve over time, reducing technical inefficiency. The estimated parameters for complementary adaptation strategies are also negative and significant, implying a more potent combination of alternative adaptation techniques used on individual farms, improved farm adaptability to climate change, and reduced paddy production inefficiency.

Table: 5, Summary Statistics of Output and Various Inputs in The Stochastic Frontier Production Function

Variables	Wayanad (No of observation138)					Palakkad (No of observation 192)				
	Per acre	Mean	SD	Min	Max	Per acre	Mean	SD	Min	Max
Paddy Output	1840.2	4194.5	5719.6	500.0	55660.0	1943.3	5767.9	6510.2	350.0	46000
The area under paddy (acre)	297.85	2.2	2.7	0.3	25.3	604.5	3.0	3.2	0.4	23.4
Seed (kg)	33.6	72.5	116.3	6.0	1163.0	41.22	129.8	168.2	14.0	1800.0
Total human labour (Man days)	32.9	71.0	59.8	7.5	379.5	76	239.4	869.0	26.0	11827
Organic Fertilizer(kg)	730	1575.5	1689.8	0.0	10000.0	317	998.4	1774.9	0.0	15000.0
Inorganic Fertilizer(kg)	112.6	243.0	318.6	0.0	2530.0	176.7	556.6	559.9	35.0	36000.0
Total Machine Labour (Hours)	8.4	18.2	24.1	2.8	227.7	6.8	21.3	33.8	2.0	410.0
Plant Protection(liters)	0.42	0.9	2.4	0.0	25.0	0.29	0.9	1.1	0.0	7.0
							Technical Efficiency Factors			
Education(years)		9.1	2.9	1.0	17.0		9.0	3.7	0.0	15.0
Household Size		4.5	1.8	1.0	11.0		4.3	1.9	1.0	10.0
Age (years)		55.1	10.8	22.0	80.0		59.7	11.0	29.0	83.0
Experience (years)		32.6	15.0	1.0	70.0		27.3	17.3	1.0	69.0
Complementary Adaptation practices		5.1	1.5	2.0	9.0		3.2	1.6	0.0	7.0
Complementary Coping Strategies		5.8	1.5	2.0	9.0		6.1	1.4	2.0	9.0

Source: Primary Data, April, May 2021.

For Wayanad, estimated parameters such as household size, experience, and coping techniques are positive, implying that increasing any of these factors increases technical inefficiency. As household size increases, anticipation of future fragmentation of landholding may affect the operation of current paddy cultivation, reducing farm production efficiency in the Wayanad study area. Contrary to the expected relationship between experience and technical inefficiency, the present study found a positive and significant relationship in the Wayanad study area. The fact that the estimated coefficient for complementary coping strategy is found positive and significant suggests that the complementary coping methods used by paddy farmers in their fields may not be a good mix of tactics, thereby increasing inefficiency in the Wayanad research area.

Table: 6, Maximum likelihood Estimate of (MLE) the Stochastic Frontier Production Function

	Wayanad		Palakkad	
Production Model				
Variables	Coefficients	P>IzI	Coefficients	P>IzI
Farm Size	0.91202	0	0.7445	0
Labour (Man days)	0.1484	0	-0.05	0.174
Seeds (K.G.)	0.03002	0	0.0789	0.151
Manure (K.G)	0.0306	0	0.050507	0.0775
Machine Labour (Hours)	-0.195	0	0.1149	0.069
Plant Protection (Litters)	-0.001	0	0.045237	0.168
Return to scale	0.92504		0.984044	

Estimated parameters for the production model with reference to the Palakkad district show that only farm size significantly affects paddy output. Although not significant, all other inputs used except labour man-days positively affect the paddy output. Palakkad paddy output production is subjected to constant returns to scale at 0.984. as the coefficient value. Estimated parameters for the inefficiency model with reference to the Palakkad study area shows that household size, age, adaptation, and coping strategies adopted have a negative but not significant impact on the technical inefficiency in paddy cultivation. It implies that an increase in factors such as household size, age, combined adaptation and coping strategies has positive effects on increasing efficiency in paddy cultivation. At the same time, education level and experience positively impact the technical inefficiency in the Palakkad study area compared to the Wayanad study area. However, not significant adaptation practices

Table;7 MLE Result for the Efficiency model

Efficiency model				
	Wayanad		**Palakkad**	
Variables and coeeficients	**Coefficients**	**P>IzI**	**Coefficients**	**P>IzI**
Education Level	-0.09002	0	0.025646	0.437
Household Size	0.009297	0	-0.06233	0.131
Age	-0.4467	0	-0.08366	0.436
Experience	0.054863	0	0.07466	0.001
Adaptation Practices	-0.008	0	-0.02587	0.289
Coping Strategy	0.32	0	-0.05825	0.467
Diagnostic Parameters				
Mean technical inefficiency	-0.1645	0.002	-0.17	0.66
Insigma2	-2.31	0	0.2988	0.893
Igtgama	29.3	0.801	5.1771	0.02
Sigma2	0.098727		2.9873	
Gamma	1		0.012455	
Sigma_u2	0.0987		2.9872	
Sigma_v2	1.69E-14		0.001719	

Source: Primary Survey. Author Calculation

and coping strategies adopted have more effects on increasing paddy cultivation efficiency. However, with reference to the Wayanad study area, adaptation strategies significantly increase the technical efficiency of paddy cultivation.

Summary, Conclusion and Policy Implication

The concept of sustainable development dates back to 12th century, however the term has been stared to use in a contemporary sense since the publication on Brundtland report on sustainable development in 1987. IPCC in all its assessment reports since 1990s undoubtedly states about the reality of the ongoing climate change because of various evidence observed all over the world. Every sector of the economy will be adversely affected by the ongoing climate change, however agriculture sector will be particularly vulnerable to climate change as it is the climate depended sector. In this context, FAO and UNFCCC emphasized that agriculture sector will be sustainable when it can cope and adapt to the climate change. In the context of climate change, agriculture sector ability to cope and adapt to the climate change will influence the efficiency of the production and hence likely to be more sustainable in the future.

Therefore, the study made an attempt to understand the role of adaptation practices and coping strategies on technical efficiency of paddy cultivation in Kerala. Before going to the analysis of the technical efficiency effects of the adaptation strategies and coping strategies to the climate change, the study made an attempt to understand the farmers perception about the ongoing climate change. Analysis of the perception about the climate change shows that, around 80 % of the paddy farmers in Palakkad and Wayanad agreed on the occurrence of ongoing climate change. Majority of the paddy farmers perceived an increasing nature of changes in the present temperature and rainfall from the long-term average changes. High degree of temperature, incident of drought, excess rainfall, delay in rainfall, drought are the dominant climate change factors perceived by the paddy farmers in both Wayanad and Palakkad. Making delay in sowing is the common coping strategy in Wayanad study area which is in response to late arrival of rainfall: Whereas, continuous cropping, transplanting and summer ploughing are common coping strategies by the Palakkad paddy farmers. Changes in cropping pattern and shifting from crops to tree crops are the common adaptation practices in Wayanad, whereas, changes in cropping pattern, lively hood diversification to non-farm employment is common adaptation practices in Palakkad. Complementary adaptation and coping strategy in study area shows majority of the farmers adopted to 4 to 7 number of practices and strategies at a time in their farm to cope and adapt to climate change. Maximum likelihood estimate for the efficiency model for the SFA reveals that, level of education, age of the farmers, adaptation practices to climate change increasing the efficiency in paddy cultivation in Wayanad, whereas, although not significant, adaptation practices, coping strategies, size of the households, age of the farmers increases the efficiency of paddy cultivation in Palakkad.

The function of farmers collectives such as Padashekhara Samithies may be strengthened further by the responsibility of disseminating information about the early warning system with climate variability and changes to the farming community. It is essential to implement long-term policy programmes in the form of by strengthening canal irrigation infrastructure on a priority basis because adoption of coping strategies to climate change depends in large part on the existence of adequate adaptation policies to climate change by public authorities. In order to avoid conflict in their employment of complementary coping and adaptation methods to climate change, there should be an effective awareness programme for paddy farmers regarding the adoption of suitable mix of coping strategies and adaptation measures. The proper implementation of state action plans on climate change may strengthen adaptation practises and coping strategies.

Incorporation of efficiency effect of adaptation to climate change on farm output is an emerging area of research, however inclusion of both adaptation to climate change and coping strategies to climate change on the efficiency effect is a first attempt in this area of research. Although not significant, both adaptation and coping strategies to climate change have an effect on reducing inefficiency in paddy cultivation in Palakkad, whereas only adaptation strategies to climate change has significant impact on the paddy cultivation in Wayanad. Therefore, study recommend importance of adaptation practices and coping strategies in the farm level planning. Since adoption rate of coping strategies among Wayanad paddy farmers is lower, moreover coping strategies are addressed for the short-term basis, it is imperative to provide early extension services to farmers in the form of dissemination of information with early warning about meteorological and climate change factors.

This study deals with agricultural sustainability in the context of climate change. The concept of agricultural sustainability is multi-dimensional and involves a complex interaction among its components, such as economic, social, and environmental. The present study's operational definition of agricultural sustainability is limited by climate change and contextual and locational specificity of factors. Hence, agricultural sustainability is looked at only through the prism of regional-specific indicators where economic and environmental components put more weight. The concept of adaptation and coping strategies is more comprehensive and operates beyond the context of climate change consideration; the present study concentrated on those adaptation and coping strategies adopted by the paddy farmers specific to climate change adjustment. Since time series data for adaptation and coping strategies are not available, the study resorts to qualitative data where multiple responses of the respondents' have been employed to extract variables for adaptation and coping strategies. The scaling techniques with more comprehensive coverages and weighting to capture more and more accuracy in the variable used for adaptation practices and coping strategies may be considered for further study in this area.

Reference

1. Aigner, D., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. Journal of econometrics, 6(1), 21-37.
2. Adzawla, W., & Alhassan, H. (2021). Effects of climate adaptation on technical efficiency of maize production in Northern Ghana. Agricultural and Food
3. Aswathy, N., Narayanakumar, R., Shyam, S. S., Vipinkumar, V. P., Kuriakose, S., Geetha, R., & Harshan, N. K. (2013). Total factor productivity growth in marine fisheries of Kerala. Indian Journal of Fisheries, 60(4), 77-80.
4. Auci, S., & Vignani, D. (2014). Climate change effects and agriculture in Italy: a stochastic frontier analysis at regional level.
5. Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical economics, 20(2), 325-332.
6. Battese, G. E., & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India. Journal of productivity analysis, 3(1), 153-169.
7. Chaudhary, S. (2012). Trends in total factor productivity in Indian agriculture: state-level evidence using non-parametric sequential Malmquist index (No. 215).
8. Conway, G. R. (1985). Agroecosystem analysis. Agricultural Administration, 20(1), 31-55.
9. Cordonier Segger, M. C., & Khalfan, A. (2004). Sustainable development law: principles, practices and prospects.
10. Desai, B. M., & Namboodiri, N. V. (1997). Determinants of total factor productivity in Indian agriculture. Economic and Political Weekly, A165-A171.
11. Dholakia, R. H., & Dholakia, B. H. (1993). Growth of total factor productivity in Indian agriculture. Indian Economic Review, 25-40.
12. Ehnert, I., & Ehnert, I. (2009). Sustainable human resource management. Physica-Verlag.
13. Fan, S., Hazell, P. B., & Thorat, S. (1999). Linkages between government spending, growth, and poverty in rural India (Vol. 110). Intl Food Policy Res Inst.
14. Food and Agriculture Organization (FAO). (2017). A literature review on frameworks and methods for measuring and monitoring sustainable agriculture.
15. Gray, R. (1991). Economic measures of sustainability. Canadian Journal of Agricultural Economics/Revue Canadienne d'Agroeconomie, 39(4), 627-635.
16. Grober, U. (2007). Deep roots: A conceptual history of 'sustainable development' (Nachhaltigkeit). [Publisher information not included in APA style].
17. Hanson, J. C., Kauffman, C. S., & Schauer, A. (1996). Attitudes and practices of sustainable farmers, with applications to designing a sustainable agriculture extension program. Journal of Sustainable Agriculture, 6(2-3), 135-156.
18. Ho, T. T., & Shimada, K. (2019). The effects of climate smart agriculture and climate change adaptation on the technical efficiency of rice farming—an empirical study in the Mekong Delta of Vietnam. Agriculture, 9(5), 99.
19. Huang, C. J., & Bagi, F. S. (1984). Technical efficiency on individual farms in Northwest India. Southern Economic Journal, 108-115.
20. Janaiah, A., Otsuka, K., & Hossain, M. (2005). Is the productivity impact of the Green Revolution in rice vanishing? Empirical evidence from TFP analysis. Economic and Political Weekly, 5596-5600.
21. Joshi, P. K., Birthal, P. S., & Minot, N. (2006). Sources of agricultural growth in India: Role of diversification towards high-value crops (No. 596-2016-40010). International Food Policy Research Institute.

22. Joshi, P. K., Kumar, P., Johansen, C., & Asokan, M. (1998). Sustainability of rice-wheat based cropping systems in India: Socioeconomic and policy issues. Economic and Political Weekly, A152-A158.
23. Kalirajan, K. P., & Shand, R. T. (1999). Frontier production functions and technical efficiency measures. Journal of Economic Surveys, 13(2), 149-172.
24. Karunakaran, N. (2014). Paddy cultivation in Kerala–Trends, determinants and effects on food security. Artha Journal of Social Sciences, 13(4), 21-35.
25. Kumar, P., Joshi, P. K., Johansen, C., & Asokan, M. (1998). Sustainability of rice-wheat based cropping systems in India: Socioeconomic and policy issues. Economic and Political Weekly, A152-A158. (This reference appears twice. You may want to check your original list for duplicates.)
26. Kumar, S., & Sidana, B. K. (2019). Input-use efficiency of adopters of climate resilient technologies in paddy and wheat crop in Punjab agriculture. Clim Change Environ Sustain, 7(1), 51-60.
27. KSAPCC. (2014). Kerala, State Action Plan on Climate Change. Govt. of Kerala, Dept. of Environment and Climate Change.
28. KSAPCC. (2008). Response to Climate Change: Strategy and Action, State Action Plan on Climate Change. Dept. of Environment and Climate Change, Govt. of Kerala.
29. Ninan, K. N., & Chandrashekar, H. (1993). Green revolution, dryland agriculture and sustainability: Insights from India. Economic and Political Weekly, A2-A7.
30. Makki, M. F., Ferrianta, Y., & Suslinawati, R. (2012). Impacts of climate change on productivity and efficiency paddy farms: Empirical evidence on tidal swamp land South Kalimantan Province–Indonesia. Journal of economics and sustainable development, 3(14), 66-72.
31. Meeusen, W., & van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. International economic review, 435-444
32. Mohan, R. (1974). Contribution of research and extension to productivity change in Indian agriculture. Economic and Political Weekly, A97-A104.
33. Otitoju, M. A., & Enete, A. A. (2014). Climate Change Adaptation Strategies and Farm-level Efficiency in Food Crop Production in Southwestern, Nigeria. Tropicultura, 32(3).
34. Office of the Registrar General & Census Commissioner, India. (2011). Census of India 2011: Provisional population totals. Ministry of Home Affairs, Government of India.
35. Owoeye, R. S. (2020). Comparing climate adaptation strategies on technical efficiency of cassava production in Southwest, Nigeria. Agricultural and Resource Economics: International Scientific E-Journal, 6(1868-2020-930), 62-75.
36. Philander, S. G. (2008). Encyclopedia of global warming and climate change: A.E. (Vol. 1). Sage Publications.
37. Pradhan, K. C., & Mukherjee, S. (2018). Examining technical efficiency in Indian agricultural production using production frontier model. South Asia Economic Journal, 19(1), 22-42.
38. Pretty, J. (2008). Agricultural sustainability: Concepts, principles and evidence. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1491), 447-465.
39. Roco, L., Bravo-Ureta, B., Engler, A., & Jara-Rojas, R. (2017). The impact of climatic change adaptation on agricultural productivity in central Chile: A stochastic production frontier approach. Sustainability, 9(1), 1-16.
40. Rosegrant, M. W., & Evenson, R. E. (1992). Agricultural productivity and sources of growth in South Asia. American Journal of Agricultural Economics, 74(3),
41. Shanmugam, K. R., & Venkataramani, A. (2006). Technical efficiency in agricultural production and its determinants: An exploratory study at the district level. Indian Journal of Agricultural Economics, 61(902-2016-68012).
42. State Planning Board, Government of Kerala. (2018). Kerala economic review 2018. State Planning Board, Government of Kerala.
43. Vijayasarathy, K., & Ashok, K. R. (2015). Climate adaptation in agriculture through technological option: Determinants and impact on efficiency of production. Agricultural Economics Research Review, 28(347-2016-17174), 103-116.