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Millets Harvest: Unveiling Agriculture's Sustainability Impact

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Abstract

Sustainability of agriculture is the utmost requirement for every country as it protects the environment, expands the earth's natural base, and maintains soil fertility without compromising the needs of the future generation. Agriculture's sustainability relies on economic, social, and environmental dimensions. Millets, in the recent era, have been gaining attention as they are considered highly sustainable crops because they are drought-resistant, requiring less water and emitting lesser greenhouse gases compared with other crops. This study analyses the impact of ecological parameters of agriculture sustainability, i.e. per capita CO2 emissions, average monthly temperature, and precipitation on the annual yield of millets in India from 2004 to 2019. The empirical findings of the time series analysis using Autoregressive Distributed Lag (ARDL) for short-run and long nexus between the climate factors and millet yield and stability test have been covered, and to check the stability of the model Cumulative Sum of Residuals (CUSUM) and Cumulative Sum of Square of Residuals (CUSUMSQ) have been used, which shows a strong relationship among the variables of the study. The results showed that the per capita CO_2 has a positive impact on the yield of millets. However, the average mean temperature negatively and significantly affects the output level of millets. The negative impact of rising average mean temperature was strong and it reduced the total yield of millets by 5% in the short-run while the impact was found to be weakly negative in the long-run. Hence, to increase the production of millets in India efforts should be made to control the average mean temperature, which is the biggest challenge for developing countries like India.

Keywords: Agriculture Sustainability, Millets, GDP, Climate Change, CO_2 Emission

JEL Codes: Q01, Q54, C01, C22

INTRODUCTION

Climate change is upon us and the effects are starting to be seen. This includes rising sea levels, flooding, salt intrusion, more frequent and intense storms, pests, and water scarcity, which keeps the amount of arable land limited, reduces agricultural yields, and jeopardises farmers' capacity to provide for their families (Wang et al., 2017). Because of climate change, there is a great deal of uncertainty and an unpredictable future for the agricultural sector. Post globalisation, the world has been witnessing more episodes of heat waves, droughts, floods, scattered precipitation, and other extreme events due to the abnormally high temperature rise (Arora, 2019). Variations in yield are influenced by a variety of factors, including crop-specific production variations, climate scenarios, adaptability, and assumptions about the CO_2 fertilisation effect. Climate change will cause the depletion of water resources in many places. Declining precipitation and rising temperatures have the potential to significantly increase the amount of water required for irrigation. (Karimi et al., 2018). The quality and availability of water and soil can be directly impacted by climate change, which can hurt crop productivity and food systems, particularly for major cereals such as maize, wheat, and rice (Saxena et al., 2018).

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India's agriculture sector, relying on diverse climatic conditions and a significant workforce share, is especially vulnerable to climate change. The impacts of these changes are increasingly evident in the country's cropping system. Research suggests that a 1°C rise in temperature could result in a 6–8% decline in wheat yields and a 4–6% reduction in rice yields. Birthal et al. (2009) evaluated how sensitive Indian agriculture is to climate change using panel data at the district level. The results also indicated that while rainfall, unless it is excessive, tends to offset the negative effects of temperature, rising temperatures would decrease agricultural productivity. The Indo-Gangetic Plain, a vital agricultural region, is particularly at risk. With nearly 70% of annual rainfall coming from the monsoon, India's agriculture is highly dependent on its patterns. Delayed onset, early retreat, and uneven distribution of monsoon rains disrupt planting cycles and crop development. The over-extraction of groundwater for irrigation, coupled with declining rainfall in key agricultural states such as Punjab and Haryana threatens the sustainability of farming practices. Farmers are increasingly compelled to transition from traditional crops such as rice and wheat to more resilient options like millets.

Millets are a sustainable source of agriculture due to multiple advantages. Millets require less water and are drought-resistant. They require less input and also less usage of chemical fertilisers. They offer an added advantage of biodiversity preservation. A group of genetically varied cereal species, known as minor millets, is suited to a variety of marginal growing environments in which major cereals such as wheat, rice, and maize are not as successful (Padulosi et al., 2015). Encouraging and prioritising millet farming can foster an environmentally sustainable agriculture sector in India.

The concept of sustainability includes all three facets – economic, social, and environmental. The objectives of sustainable development seek to advance peace and co-operation while eradicating poverty, safeguarding the environment, and ensuring prosperity for all. They offer a thorough framework to direct countries and interested parties in their endeavours to create a future that is more equitable and sustainable. Many of the Sustainable Development Goals (SDGs) are interconnected and mutually supportive when we consider millets' role in accomplishing them. It is interesting to note that by bridging customs and cultures, millets emerge as a common thread that can help accomplish multiple objectives at once. Patil et al. (2023) highlighted the importance of millets in achieving sustainability goals and also highlighted the healthy aspect of millets as they are nutrient-rich superfoods.

There is a dearth of literature on the analysis of agricultural sustainability, specifically environmental sustainability on per capita yield production on millets. The present study tries to fill this research gap by examining the impact of climate factors, which are essential components of agriculture sustainability, on the production of millets in India.

REVIEW OF LITERATURE

This section focuses upon the most cited and famous global studies that have analysed the impact of climate changes and factors affecting agriculture sustainability on crop yield such as cereal crops (i.e. wheat, rice, millet, and so on). Most of the studies used simulation and regression techniques to examine the impact of environmental factors on crop yield. Terjung et al. (1984) and Eitzinger et al. (2001) followed some of the studies that used simulation techniques. Isik and Devadoss (2007) empirically tested the impact of climate change on crop yields and its yield variability and showed the modest effect of temperature and precipitation on crop yield. Rice, wheat, and other cereals were found to be sensitive to climate and agronomic management in Pakistan (Arshad et al., 2016). Guntukula (2019) performed the analysis to capture the impact of climate change on major food and non-food crops in India. The study suggested major policy changes to enhance the resilience of Indian agriculture and furthermore laid emphasis on growing more sustainable crops. Khan and Jadaun (2022) investigated how climate change affects millet yield in India for secondary data spanning from 1991 to 2020. India's average annual temperature, precipitation, CO_2 emissions per person, and rural population were used to estimate the variation in agricultural millet production utilising the enhanced Dickey-Fuller (ADF) and unit root test to evaluate the order of integration. The study showed that while CO_2 emissions per capita have a positive long-term impact on millet yield, average annual temperature has an adverse and significant effect on millet yield. India's growing population will cause problems for the country's food security. Strategies are required to lessen the detrimental effects of temperature on agricultural productivity and ensure there is enough food for a growing population. Numerous organisations have created frameworks for estimating agricultural sustainability, with some variations among them. These organisations include the World Bank, the Organisation for Economic Co-operation and Development (OECD), the United Nations, and the European Environment Agency (EEA). Dwivedi et al. (2023) in their study highlighted the sustainability aspect of millets, focusing on agricultural sustainability. The study defined the benefits of millet farming for the environment including the crop's resilience to drought, economical use of water, improved soil quality, preservation of biodiversity, and reduced chemical use. Because of these qualities, millets are resistant to climate change, help preserve water, increase soil fertility, and promote the diversity of agroecosystems. Mishra (2023) suggested the importance of millets amid the climate change that is ongoing. A key component of sustainable agriculture is a production method that places a high value on maintaining the health of the soil, human welfare, as well as ecological integrity. It is based on the ideas of ecology, fairness, health, and caring, and its main goal is to cultivate land and raise crops in a way that enhances soil health and general well-being. Furthermore, millet crops require about 80% less water than other crops such as rice, wheat, or sugarcane, exhibiting a significantly smaller water footprint. The growing popularity of millets has been largely attributed to their improved adaptability to a variety of cropping systems and their capacity to be modified in contingency plans during the uncertainties of the monsoon season. Raj et al. (2024) examined the many advantages of millets for managing soil nutrients, showing how they can flourish in low-nutrient environments and increase soil fertility by enhancing soil structure and adding organic matter. Adding millets into intercropping and crop rotation schemes is emphasised as an environmentally friendly approach that boosts soil biodiversity and lessens the need for chemical inputs. Millets are a strategic crop for climate change adaptation due to the lesser volume of water required and drought resistance, which are important in areas with limited water resources. investigates the socioeconomic effects of millets farming as well.

DATA SOURCES AND SPECIFICATION OF VARIABLES

The variables mentioned in Table 1 have been selected after a systematic literature review of the studies Arora (2019) and Surendra et al. In the present study, the analysis has been done based on secondary data considering only the environmental aspect of agricultural sustainability where a relationship between total yield of millets and carbon emissions per capita, precipitation, and average mean temperature from 2001 to 2019 has been studied.

Table 1: List of Variables, Description, and Respective Data Sources

Name of the Variables	*Description of the Variables*	*Data Sources*
$PCCO_2$	CO_2 emissions (per capita)	Our World in Data
PRE	Precipitation (mm)	World Bank Group (WBG), Climate Change Knowledge Portal, and World Development Indicators (WDI)
AMT	Average mean temperature (°C)	WBG and WDI
TMP	Total millets production (yield per hectare): minor, jowar, bajra, and ragi	Indian Council of Agricultural Research (ICAR)

Note: All the variables are in log form.
Source: Author's contributions.

METHODOLOGY

The present study used the most famous time series test, the ADF, to check the stationarity of the time series. Further, the Autoregressive Distributed Lag (ARDL) model will be used to capture the short- and long-run impact of the explanatory variables.

ADF

The ADF test was propounded by David A. Dickey and Wayne A. Fuller in 1979. It is an extension of the original Dickey-Fuller (DF) test developed in 1976, designed to handle more complex models with higher-order autocorrelation by including the lagged series. The ADF test is a statistical test used to check for the presence of a unit root in a time series, which helps determine whether the given series is stationary or non-stationary. The null hypothesis (H0) assumes the presence of a unit root (non-stationary). Rejecting the null hypothesis after evaluating the tau-statistics (ADF-T statistics), it helps the researchers conclude that the series is stationary.

ARDL Model

The ARDL is a widely used model of time series analysis to study the dynamics of the variables. Pesaran and Shin (1995, 1998) and Pesaran et al. (1996, 2001) have propounded this model. This model has its advantage over other techniques of time series, which include Johansen (1988), Johansen-Juselius (1990), and Gregory-Hansen (1996). The Johansen model of cointegration is only applicable when all the series integrated are of the same order. However, the ARDL can be applied irrespective of this condition. The second advantage is that it can provide significant results even in a small sample although the results will be more appropriate in the case of a large sample.

The general form of the ARDL is:

$$y_t = \alpha_0 + \beta_1 x_t + \sum_{i=1}^{n} \partial_i y_{t-i} + \sum_{i=1}^{n} \delta_i x_{t-i} + u_i \qquad \text{Eq. (1)}$$

Here y_t = dependent variable

x_t = explanatory variable

y_{t-i} = lagged terms of y_t

x_{t-i} = lagged terms of x_t

u_i = residual term

In bounds testing, researchers set upper and lower bounds for a test statistic, typically the F-statistic, to estimate if a prolonged relationship exists among the variables of interest. The bounds are determined based on critical values from a distribution, often the F-distribution. In essence, bounds testing provides a framework for assessing whether variables are cointegrated, indicating a stable long-run relationship. It allows researchers to understand the dynamics of relationships among variables over time, which is crucial for many economic and financial analyses.

Empirical with Results

The present study objective can be fulfilled with the ARDL to capture the short-term and long-term effects of environmental variables on the yield of millets in India (Nasrullah et al., 2021, Jadaun et al., 2022). The stationarity or unit root testing of all variables was constructed using the ADF test and as per the results, some of the series were found to be stationary at level and at first difference. All the variables are in log form and the double log model was used to make interpretations of estimates in the form of elasticity.

$$\ln TMP_t = \partial_0 + \partial_1 \ln AMT_t + \partial_2 \ln PRE_t + \partial_3 \ln PCCO2_t + u_t \qquad \text{Eq. (2)}$$

The unit root testing results using the ADF have been illustrated in Table 2. All the variables exhibited stationarity at level except the TML series, i.e. stationary at first difference without trend. The PCCO2 and PRE were found to be level stationary including both trend and intercept.

Table 2: Empirical Results of ADF – Unit Root or Stationarity

Name of Variable	*Order of Integration*	*Model*
ln AMT	I (0)	With intercept only
ln TMP	I (1)	Without trend and intercept
ln PRE	I (0)	With trend and intercept
ln $PCCO_2$	I (0)	With trend and intercept

Note: I (0) – level stationary and I (1) – first difference stationary.

Source: Estimation using EViews 10.

The ARDL – no constant and no trend model takes only one lag of the variables. The ARDL equation of the present study is illustrated in Eq. 3.

$$\ln TMP_t = \partial_1 \ln AMT_t + \partial_2 \ln PRE_t + \partial_3 \ln PCCO2_t + \sum_{i=1}^{n} \propto_i \ln AMT_{t-i} + \sum_{i=1}^{n} \delta_i \ln PRE_{t-i} + \sum_{i}^{n} \varepsilon_i \ln PCCO2_{t-i} + \sum_{i}^{n} \phi_i \ln TMP_{t-i} + u_t$$

Eq. (3)

Long-Run Result of ARDL

In Table 3 the value of F-statistics of Long-Run and Bound Test – 11.75, was found to be statistically significant at 5% confidence bound.

Table 3: Empirical Findings of Long-Run and Bound Test in ARDL

F-Statistics	*Values*	*Significant*	*I (0)*	*I (1)*
	11.75	10%	2.37	3.1
	3	5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

Source: Estimation using EViews 10.

The F-statistics exceeds the upper bound both at 5% and 10%. Hence, the null hypothesis has been rejected; this indicated the long-run relationship between the production of millets and environmental factors of agriculture sustainability. The long-run results of the ARDL – restricted constant model are illustrated in Table 4. The study demonstrated that all the environmental sustainability factors of the present study have a significant effect on the total yield of millets. The estimated value of per capita CO_2 emissions was coming out to be a positive 3.67, implying that in the long-run if $PCCO_2$ consumption increased by 1% it may lead to an increase in the total yield of millets by 3.6%. Similarly, PRE is also affecting millets production favourably and significantly in the long-run. The production of millets will likely increase by 0.6% in the long-run if there is a 1% increase in the level of precipitation in the environment (Haque, 2022). However, the average mean temperature is negatively and significantly affecting the output level of millets. It has been estimated that a 1% increase in the average mean temperature of the earth leads to a reduction in the yield of millets by 1.5%. The empirical finding favours that policy should be structured to control global warming.

Table 4: ARDL Long-Run Results of No Constant and No Trend Model

Variables	*Coefficients*	*Std Error*	*T-Statistic*	*Prob*
LNAMT*	-1.5504165	0.388382	-4.756738	0.0021
LNPCCO2*	3.670643	0.377381	9.726633	0.0000
LNPRE*	0.606675	0.192611	3.149745	0.0092

Note: The * signifies the variables are significant at a 5% confidence interval.

Source: Estimation using EViews 10.

Short-Run ARDL Error Correction Mechanism (ECM)

All environmental factors significantly impact the yield of millets in India, both in the short term and the long term. The signs of all the estimated coefficients were similar in both periods but the impact of all three factors on the yield was found to be strong in the short-run compared with the long-run. Precipitation has a weak positive impact on the yield in both the short- and long-run compared with per capita CO_2 emissions. The Cointegration Coefficient illustrated in Table 5 must be negative and significant as per the ARDL model; hence it also satisfies both conditions, which implies that if there are any random shocks that occur in the economy the disequilibrium will likely be corrected by -1.52.

Table 5: ECM: Results of ARDL (Short-Run)

Variable	Coefficient	Std Error	T-statistics	Prob
D(LNAMT)	-5.30	1.167	-4.547	0.00008
D(LNCCO2)	8.152	2.272	3.587	0.0043
D(LNPRE)	0.454	0.104	4.373	0.0011
Coint Eq(-1)	-1.52	0.20	-7.542	0.000

Note: D defines the difference of the variables.

Source: Estimation using EViews 10.

The average yearly temperature has a more unfavourable impact on the production yield in the short-run compared with the long-run. A 1% increase in yearly average mean temperature will lead to a fall in production by 5.3%.

Table 6: Short-Run ECM Statistics Value

R square	0.88	Akaike info criterion	-2.969
Adjusted R square	0.86	Schwarz criterion	-2.77
Durbin-Watson stat	2.25	S E of regression	0.049
Log likelihood	30.72	Hannan-Quinn criteria	-2.942

Source: Estimation through EViews 10

The R^2 and Adjusted R^2 values in Table 6, were found to be 0.88 and 0.86, indicating that more than 85% variation in the dependent variable, i.e., annual yield of millets in India, was explained by all the three explanatory variables. The Durbin-Watson stat value was also closer to two, which shows the absence of autocorrelation in the model. The value of standard error was found to be approximately zero and log likelihood (F-statistics) value of the model was very large, implying that the model's goodness of fit was high. The overall results of the long- run as well as the short demonstrated that the yield of millets in India is significantly affected by environmental factors.

Stability Test

The CUSUM (Cumulative Sum of Residuals) and CUSUMSQ (Cumulative Sum of Square of Residuals) tests have been used to check the stability of the estimated coefficients of the ECM model. If the estimated CUSUM and CUSUMSQ graph lies in the significance bound it implies that the model is stable and the relationship among explanatory variables and dependent variable is meaningful. The blue line in Fig. 1 and Fig. 2 lies between the 5% significance confidence limits represented by red lines. Both graphs justify an absence of instability in the present model. The graph of CUSUMSQ shows more deviation from zero than CUSUM.

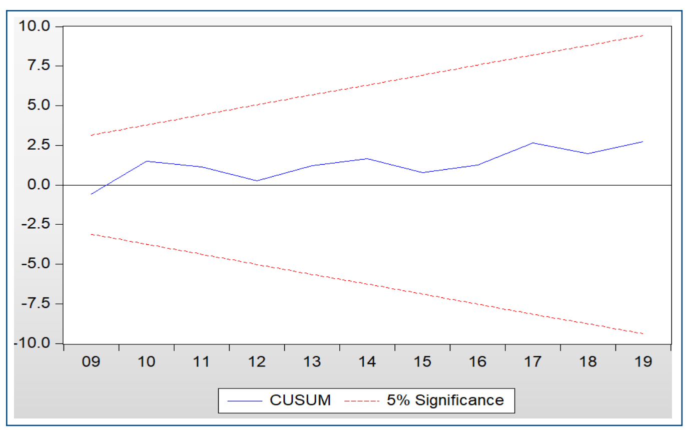

Fig. 1: Graph of CUSUM Based on Estimates of ECM

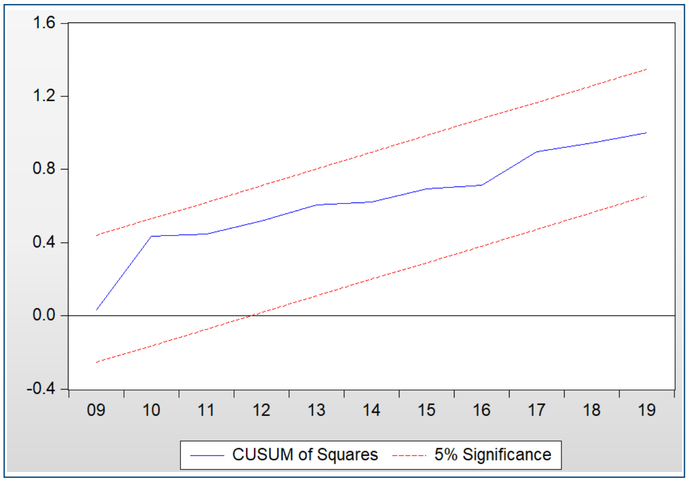

Fig. 2: Graph of CUSUMSQ Based on Estimates of ECM

CONCLUSION

The study empirically tested the presence of short- and long-run relationships between the environmental factors of agriculture sustainability and the total millet production in India from 2001 to 2019. Based on ARDL modelling and the ECM, there is a significant relationship among variables. It has been observed that there exists a strong positive impact of per capita CO_2 emissions on the yield of millets in India in the short-run compared with the long-run. A small positive significant impact of precipitation has been observed in both periods. The average yearly temperature of India negatively affects the production yield in both the short-run and long-run. The negative impact of rising average mean temperature was strong and it reduced the total yield of millets by 5% in the short-run while the impact was found to be weakly negative in the long-run. Hence, to increase the production of millets in India efforts should be made to control the average mean temperature, which is the biggest challenge for developing countries like India. The findings reveal that environmental sustainability is a prerequisite to increasing the production of agriculture-sustainable crops such as millets due to a strong interlinkage between the two.

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