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Building Climate-Resilient Agricultural Systems through Sustainable Resource Management in the Global South

Arshad Bhat
bhatarshad09@gmail.com

Amity University Mumbai
Abid Sultan
Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir
Abid Qadir
Glocal University
Aamir Qureshi
Department of School Education, Jammu and Kashmir
Iqra Qureshi
Central Institute of Temperate Horticulture

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Abstract

Climate change has a very grave and multidimensional menace to the agricultural systems of the Global South where livelihoods are heavily dependent on natural resources that are sensitive to climatic parameters. The paper will discuss sustainable resource management as one of the solutions to establishing climate-resilient agricultural systems, and in particular, water-use efficiency, soil conservation practices, and application of climate-smart agriculture. With the aid of the fixed-effects and system GMM estimations, the analysis of the impact of climatic variability and resource management policies on the agricultural productivity is measured by using panel data of selected economies in the Global South between 2000–2022. The results show that fluctuation in rainfalls and temperature variations is interrelated in delivering low crop yield, but successful water management, effective soil utilization, and adoption of agriculture sensitive to climate are very positive. It is also estimated by interaction that sustainable resource management reduces the negative impacts of climatic stress, and hence, agrarian resilience is enhanced. The findings indicate that integrative resource control, institutional support and policy model flexibility are important in enhancing agricultural sustainability amid increasing climate uncertainty. The study offers empirically grounded data on the policymakers that are keen on enabling resilient and sustainable agricultural transformation in the Global South.

Introduction

Food security, livelihoods, and rural employment in the Global South continue to rely on agriculture, but is rapidly becoming endangered by climate change, degradation of the environment, and non-sustainable use of resources. The increase in temperatures, doted rainfalls and increasing numbers of extreme weather conditions has aggravated production risks, especially in places where agriculture is mostly rain-fed and resource-based. These issues have raised the question of long-term sustainability and resilience of the agricultural systems, which contributes to the fact that the development of adaptive and resource-efficient strategies is in urgent need (FAO, 2021; IPCC, 2022).

Structural limitations in the Global South including access to technological advancements, ineffective institutional capacity, land fragmentation, and financial marginalization of smallholders contribute to living in a disproportionate contribution of climate-related agricultural vulnerability. Climate variability directly impacts on crop yield, soil fertility, and water supply hence worsening food insecurity and rural poverty (Wheeler and von Braun, 2013). Simultaneously, traditional agro-ecosystems, which are typically marked by ineffective water management, soil erosion, and excessive use of inputs, have also compromised the sustainability of the ecological environment and adaptability (Pretty et al., 2018).

Sustainable resource management has in this context become an important channel towards climate resilience in agriculture. Some of the practices include effective irrigation, soil conservation, integrated nutrient management, and climate-sensitive agriculture (CSA) to maximize the utilization of resources and minimize environmental externalities and production risks. It has been empirically found that sustainable resource management can enhance productivity and the capacity of farmers to respond to climate shocks by stabilizing productivity and preserving natural capital (Lipper et al., 2014; Altieri et al., 2015). Nevertheless, it is not yet adequately investigated how the practices can moderate the climate-induced stress in various agro-ecological and institutional contexts in the Global South.

The literature that has been published has mostly dealt with climate change consequences and adaptation measures individually, and most of them seem to be dealing with one or two practices or a region or just the consequences in the short term. The current body of cross-country empirical research, which combines both climatic variables with indicators of sustainable resource management, is relatively sparse, and the combined impact of both elements on agricultural resilience is not studied. Additionally, little has been given to the mechanism of interaction whereby the management practices of resources can reduce the negative effects of climate variability on agricultural productivity (Abegunde et al., 2019). The gap is important when it comes to formulating evidence-based policies to ensure that climate adaptation is in line with sustainable development goals.

It is based on this that this current research aims to explore the role of sustainable resource management in developing climate-resilient agricultural systems within the Global South. The research focuses on direct impacts of climate stressors, which include variability of rainfall and higher temperatures, on agricultural productivity and the mitigating nature of water-use efficiency, soil management, and the adoption of climate-smart farming practices with the help of panel data and econometric methods. Explicitly including effects of interactions, the analysis points into resilience processes which promote agricultural sustainability with growing climate uncertainty.

The results of the research would be useful in the expanding body of literature on sustainable agriculture and climate adaptation as they would provide solid empirical data regarding sustainable agriculture and climate adaptation through the prism of the Global South. Policy wise, the outcomes emphasize the need to have integrated resource governance, institutional backing and investment in sustainable agricultural practices to implement a sustainable food system. By doing so, the study will be in line with the global development agendas, such as the Sustainable Development Goals (SDGs), especially zero hunger, climate action, and sustainable land and water management.

Review of Literature

There is a large amount of literature that records the increased susceptibility of agricultural systems in the Global South to climate change. Increased temperature, higher variability of rainfalls and extreme weather have been indicated to impact negatively on crop production, moisture availability and water availability, especially in rain-fed agricultural systems (Wheeler et al, 2013). Empirical research has shown that a small rise in temperature can markedly decrease the yield of staple crops in the tropical and subtropical areas, where there is a low adaptive capacity (Lobell et al., 2011). On assessments of the Intergovernmental Panel on Climate Change, developing ones will lose agricultural production proportionally more than developed ones since natural resources that are sensitive to climate depend on them, and they have weaker institutional capacity (IPCC, 2022).

Variations in the amount of rainfall have become a fundamental factor of yield instability in the Global South. Research on panel and time-series data proves that higher unpredictability in rainfall has a negative impact on agricultural production and agricultural income, and thus it worsens food insecurity and poverty (Brown et al., 2017). The effects are also enhanced by the degradation of land, the reduction of soil fertility, and the inability to effectively utilize water, which heighten the risks of production due to climate-related factors (FAO, 2021).

The concept of sustainable resource management has been universally hailed as a symbol of tough agricultural systems. The use of soil conservation, efficient irrigation, integrated nutrient management and sustainable land use are among the practices that are designed to ensure that a balance between the ecology is maintained and the productivity is improved. Empirical information indicates that better management practices of the soil: conservation tillage, crop rotation, organic amendments enhance the yield stability and soil carbon sequestration (Pretty et al., 2018; Lal, 2020).

The concept of water-use efficiency is of great importance particularly in the Global South where the agricultural sector experiences the highest proportion of freshwater withdrawals. Research indicates that funding in effective irrigation systems and water management can immensely improve crop yields but lessen the chances of droughts (Rosegrant et al., 2020). As the Food and Agriculture Organization of the United Nations makes it clear, long-term sustainable growth in the agricultural sector requires sustainable water and soil management (FAO, 2021).

CSA has been featured as a combination strategy that considers addressing both productivity, adaptation and mitigation goals. According to Lipper et al. (2014), CSA boosts resilience by implementing adaptive practices that include stress-resistant crop systems, diversified agricultural systems, or enhanced efficiency of resource utilization. The use of CSA has been proven to enhance yield stability and minimize the downside risk of climate variability by empirical research conducted in Africa and South Asia (Abegunde et al., 2019; Aryal et al., 2020).

Nevertheless, the implementations of CSA practices are still lopsided owing to various limitations, which include the lack of access to credit, information asymmetries, and the lack of institutional backing. Research has emphasized governance, extension services and financial inclusion as the elements that help promote the spread of sustainable agricultural technologies (Kassie et al., 2015). These results emphasize the role of the quality of institutions in the transformation of resource management practices into real resilience outcomes.

The recent econometric literature has paid more attention to the quantification of the interaction between the effects of climatic stressors and resource management practices. The results of panel data show that sustainable resource management has both a direct and positive influence on productivity but also mitigates the negative effects of temperature shocks and rainfall shocks (Dell et al., 2014; Abegunde et al., 2019). Interaction models show that farms that use soil and water conservation methods have much less yield losses due to extreme climatic events.

Dynamic panel models also indicate that the persistent effect on the long-term adaptive capacity implies that the prior investments in sustainable resource management produces persistence effects (Bond et al., 2010). Nevertheless, these developments have not eliminated the fact that much of the current empirical literature is region-specific or practice-specific and finds it challenging to generalize results to the rest of the Global South.

Despite the comprehensive studies of the effects of climate change and agricultural adaptation, it has multiple gaps. To begin with, there is paucity of cross-country empirical research on integrating climatic factors with various dimensions of sustainable resource management. Second, we do not understand well the systems of interaction by which the resource management practices act as buffers to climate shocks within the macro-level econometric models. Finally, institutional and governance variables are usually seen as the control variables instead of as the constituent units of resilience-building processes.

The given research paper fills these gaps by covering them with a full-scale panel econometric study to investigate the potential of sustainable resource management as a method of improving climate resilience in the agricultural systems of the Global South. The explicit ways of modeling the climate-resource interactions make the study part of a more detailed view of resilience processes applicable to the policy-making process and the sustainable development planning.

Methodology

This research uses unbalanced panel data; this consists of a sample of Global South economies between 2000 and 2022. The inclusion of countries is based on the availability of data on agricultural production, climatic indicators, and management variables of resources. The crop yield index is used to measure agricultural productivity, and the variability in climate is defined by rainfall variability and temperatures anomaly. Proxies of sustainable management of resources are the indicators of water-use efficiency, soil conservation practices, and adoption of climate-smart agriculture (CSA). Institutional quality and availability of credit are also taken as control variables to consider governance and financial restriction effects on agricultural performance.

The data on climate is obtained on internationally accepted climate-screen sources and the data in agriculture and institutions is obtained on global development databases. All the monetary and index-based variables are standardized so that there is cross-country comparability.

Variable Definition and Measurement

Let $\varvec{i} = 1,2,\ldots,\varvec{N}$ **index countries and** $\varvec{t} = 1,2,\ldots,\varvec{T}$ **index years.**

$Yield_{it}$

Agricultural productivity index

$RainVar_{it}$

Coefficient of variation of annual rainfall

$TempShock_{it}$

Temperature anomaly (deviation from long-term mean)

$WaterUse_{it}$

Irrigation and water-use efficiency indicator

$SoilMgmt_{it}$

Soil conservation and management index

CSA_{it}

Share of farmers adopting climate-smart agriculture

$InstQual_{it}$

Institutional quality index

$Credit_{it}$

Access to agricultural credit

To examine the impact of climate variability and sustainable resource management on agricultural productivity, the following baseline panel regression model is specified:

$$\varvec{Y}\varvec{i}\varvec{e}\varvec{l}\varvec{d}_{\varvec{i}\varvec{t}} = \varvec{\alpha} + \varvec{\beta}_1\varvec{R}\varvec{a}\varvec{i}\varvec{n}\varvec{V}\varve$$

where:

μ_i captures unobserved country-specific effects,

λ_t denotes time-specific effects,

ϵ_{it} is the idiosyncratic error term.

To control time in varied heterogeneity across countries, including agro-ecological conditions and structural aspects, the fixed effects (FE) estimator is used.

To explicitly evaluate the role of sustainable resource management as a resilience-bearing process, terms of interaction between climate stressors and resource management indicators are proposed:

$$\varvec{Y}\varvec{i}\varvec{e}\varvec{l}\varvec{d}_{\varvec{i}\varvec{t}} = \varvec{\alpha} + \varvec{\beta}_1\varvec{R}\varvec{a}\varvec{i}\varvec{n}\varvec{V}\var + \varvec{\beta}_6(\varvec{R}\varvec{a}\$$

The positive and significant interaction coefficients demonstrate the fact that the negative effects of climate variability on agricultural productivity are alleviated by sustainable resource management practices.

Due to the continuation of agricultural productivity and the possible endogeneity of yield, resource management, and climate adaptation decisions, dynamic specification is estimated with the help of the System Generalized Method of Moments (System GMM):

$$\varvec{Y}\varvec{i}\varvec{e}\varvec{l}\varvec{d}_{\varvec{i}\varvec{t}} = \varvec{\gamma}\,\varvec{Y}\varvec{i}\varvec{e}\varvec{l}\varvec{d}_{\varvec{i}\varvec{t}-1} + \var$$

The System GMM estimator addresses:

Endogeneity arising from reverse causality,

Unobserved heterogeneity, and

Autocorrelation in the error structure.

Internal instruments are lagged levels and differences of the variables that are dependent. The Hansen test of over-identifying restrictions and the Arellano-Bond autocorrelation test are the two tests used to determine the model validity. Every regression uses strong standard errors to adjust the heteroskedasticity and serial correlation. Variance inflation factors (VIF) are used to test multicollinearity and unit root tests are used to test panel stationarity. Hausman specification test directs the decision of whether to use fixed and random effects. The research is also based on secondary data only and, therefore, is transparent and reproducible. Although the panel method enhances causality, there are still weaknesses in terms of quality and aggregation bias of data especially in distressing micro-levels of adaptation behavior.

Results and Discussion

Table 1 shows the most important variables that were employed to analyze the relationship between climatic stress, sustainable management of resources, and agricultural productivity in the Global south. The variables include the climatic factors, the efficiency of resource-use, institutional conditions, and adaptive capacity offering a comprehensive evaluation of the climate resilience in agriculture. The agricultural productivity as a crop yield index (2015 = 100) has an average of about 102, with 65 to 150 in the variability among the countries and years. This large variance is indicative of massive heterogeneity in production structures, level of technological usage and agro-climatic factors in the Global South. The fact that it varies in yield levels justifies the fact that it is used as a dependent variable in panel regressions since it represents both the structural variations as well as the time variations in agricultural performance.

The Rainfall variability (RainVar) or the coefficient of variation of the annual rainfall value is an average of 22 with the extremes being over 40 in the drought-prone areas. There is likely to be negative impact of increased alternation in rainfalls in agricultural productivity especially in rain-fed systems whereby, irrigation systems are yet to be fully established. Temperature anomaly (TempShock) is on average about 1.2C higher than the historical average of multiple years and had the highest anomalies of nearly 3 C in some years. Crops under these deviations are stressed by heat, and the growing periods are decreased, and yields are reduced, which is why the variable is expected to have a negative value. These indicators collectively support the exposure of Global South agriculture to climatic uncertainty and hence the need to include them as core explanatory variables. Efficient water use (WaterUse), which is proxied by irrigation efficiency, captures a mean of almost 55 percent meaning moderate but rather uneven uptake of water-efficient technologies. Higher irrigation efficiency of countries implies that the yields will be better, and the countries will be less affected by the rainfall shocks, which accounts for the positive expected sign.

The Soil conservation practices (SoilMgmt) with a scale of 0–1 index has an average of about 0.47 indicating partial implementation of practices like conservation tillage, crop rotation and organic amendments. The mean is relatively low, and this is an indication that there is a considerable amount of opportunity to enhance the health of soils, which is likely to boost productivity and resilience to climate change. Input-use efficiency (InputEff) has an index mean of nearly 0.60, indicating the inefficiency of fertilizer and seed and use of energy in most economies of the Global South. Efficiency of higher input is linked to low cost of production and less ecological strain, which justifies its positive anticipated correlation with yield.

The average adoption of climate-smart agriculture (CSA) is approximately 36 percent of farmers, but this can be as low as 4 percent in one region and as high as 72 percent in another. This is still a limited degree of adoption, but it shows an increasing awareness and slow spreading out of climate-resilient practices. The positive sign of expectation indicates the role of CSA in stabilizing yields in climatic stress. The institutional quality (InstQual) has a mean of about 0.55 that varies around the differences in the effectiveness of governance, implementation of policy and the services that are extended. The presence of stronger institutions is expected to enable the use of technology, access to credit and the management of resources in a sustainable way hence enhancing the outcomes of agriculture. Agricultural credit (Credit) access is at an average of 42 per cent of the rural households which indicates that farmers continue to experience financial limitations. Better access to credit leads to more investment in irrigation, soil conservation and climate-sensitive technologies, and being consistent with its positive anticipated effect on productivity.

Table 1
Description of Dataset and Variables

Variable	Description	Unit	Expected Sign
Yield	Agricultural productivity (crop yield index)	Index (2015 = 100)	—
RainVar	Rainfall variability (CV of rainfall)	%	–
TempShock	Temperature anomaly	°C	–
WaterUse	Efficient water use (irrigation efficiency)	%	+
SoilMgmt	Soil conservation practices index	Index (0–1)	+
InputEff	Input-use efficiency	Index	+
CSA	Climate-smart agriculture adoption	% of farmers	+
InstQual	Institutional quality index	Index	+
Credit	Access to agricultural credit	% households	+

The descriptive statistics represented in Table 2 give significant information regarding how the agricultural productivity, climate stress and adaptive capacity is distributed, varying and structured among the sampled economies of the Global South. The agricultural productivity reported in terms of crop yield index (2015 = 100) has a mean of 102.4, which means that average productivity rates are slightly higher than the mark of the base year. Nevertheless, the standard deviation of 18.7 and a large interval between 65.2 and 148.6 bring out a high cross-country and time heterogeneity. This dispersion is an indicator of the variation in agro-climatic conditions, adoption of technology, and institutional backing that show the imbalance of agricultural performance in the Global South.

Rainfall variability (RainVar) has the mean of 21.8, and the standard deviation value of 7.3 and shows that there is substantial variation in the patterns of the precipitation. Its minimum of 9.5% versus a maximum of 42.1 allows one to conclude that there are several countries with extremely fluctuating rain regimes. This variability is incredibly hazardous to rain-fed farming and will lead to negative implications, which are likely to impact negatively on crop production. The average temperature anomaly (TempShock) is 1.26o C; the values are between 0.12o C and 2.89o C. The upper bound is relatively high, which means that the

exposure to heat stress conditions exceeding historical standards is frequent. The average standard deviation (0.61 C) indicates long-term and widespread variations in temperatures, which is in support of the fear that crops are subjected to thermal pressures and the outcome is a reduced crop yield.

The mean irrigation efficiency is 54.3% in efficient water use (WaterUse), but there is a large variation among countries (Std. Dev. = 16.9). The 18.0% to 89.5% indicates severe inequalities between irrigation facilities and water management. The nations on the low end of the scale tend to be more susceptible to the rainfall shocks, but the higher the efficiency level of the country, the higher is the adaptive capacity. The Soil conservation practices (SoilMgmt) on a 0–1 index indicate that the average is 0.47 indicating moderate adoption of soil management practices. There is an unequal adoption of conservation tillage, organic amendments, and erosion control actions as shown by the spread between 0.10 to 0.91. The comparatively low mean highlights the huge opportunities to enhance soil health as a resilience-building measure.

The average of farmers adopting climate-smart agriculture (CSA) is 36.2 and its standard deviation is 15.4. The adoption rates spread at 8.0 per cent to 74.3 per cent, which implies that there are outstanding variations in awareness, institutional support and access to extension services. Although the upper limit indicates that diffusion is possible in certain situations, the small minimum depicts that barriers are still present in others. The mean of agricultural credit access (Credit) has a value of 41.7% of the households, and this is a range of 11.2 to 83.6%. The variability rate (Std. Dev. = 17.8) indicates the disparity in the financial inclusion based on regions. Reduced access to credit limits the prospects of farmers to invest in irrigation, soil conservation and climate-smart technologies thus reducing the adaptive capacity.

Table 2
Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Yield	102.4	18.7	65.2	148.6
RainVar	21.8	7.3	9.5	42.1
TempShock	1.26	0.61	0.12	2.89
WaterUse	54.3	16.9	18.0	89.5
SoilMgmt	0.47	0.19	0.10	0.91
CSA	36.2	15.4	8.0	74.3
Credit	41.7	17.8	11.2	83.6

The regression findings reveal that climate variability and temperature shock have statistically significant negative effects on agricultural productivity, whereas the practices of sustainable resource management and institutional quality have positive and resilience enhancing impact. The coefficient of Rainfall variability (RainVar) = -0.412 has significance = -4.53) is negative and significant at 1 percentage level (t = -0.4121). This means that as there is a greater increase in variability of rainfall, crop productivity will be reduced to a measurable extent. A one-unit change in the variability of rainfall is connected with an average decrease of 0.41 points in the index of crop yield, which highlights the susceptibility of the agricultural systems in the Global South to unpredictable precipitation.

Also, a strong and statistically significant negative impact on agricultural output is seen between temperature anomalies of TempShock with a coefficient being − 1.276 and t-value being − 3.82. This finding indicates that an increment of one degree Celsius in temperature variance relative to historical standards decreases agricultural efficiency by about one and twenty-eight index points. The scale of this impact is how intense the heat stress can be on crop development, and it substantiates how real the threat of increased temperatures is to agricultural sustainability.

Conversely, the effects of indicators of sustainable management of resources are always positive and significant. The coefficient in the Efficient water use (WaterUse) is recorded at 0.287, and it is significant at the 1% level at (t = 4.56), meaning that irrigation efficiency improvement greatly increases the crop yields. When water-use efficiency increases by one-percentage point, the index of the yield increases by close to 0.29 points, which highlights the significance of water management in lessening climate-related production risks (Table 3).

Soil conservation practices (SoilMgmt) are found to be one of the strongest predictors of productivity with a very high positive coefficient of 8.914 and t-value of 4.15 which is significant at the 1% level. This observation suggests that when there are better practices in regard to soil management, then there is a significant production of agricultural products. The high magnitude is indicative of the importance of the health of soil in enhancing the availability of nutrients, retention of moisture and resilience to climate stresses in the long term.

The adoption of climate-sensitive agriculture (CSA) is another positive factor that affects the productivity of agriculture and the coefficients of 0.193 are statistically significant at the 5% level (t = 2.38). This finding, although of a smaller magnitude than water and soil management variables, demonstrates that improved use of climate-smart practices leads to higher yields because it incorporates adaptive mechanisms that should help them cope with climatic variability. The coefficient of institutional quality (InstQual) is positive and statistically significant (1.527) meaning that stronger institutions are critical in facilitating agricultural productivity. Better governance, effective policies and institutional capacity allow the adoption of sustainable resource management practices and enhancement of access to support services, and, therefore, support the outcomes of resilience (Table 3).

Lastly, the constant term is also positive and of great importance (67.34; t = 6.86), which is the level of agricultural productivity at the point when all the explanatory variables have been held constant. All in all, the findings are strong empirical evidence that although climate variability is a great detriment to agricultural productivity in the Global South, the negative effects can be effectively counterbalanced through sustainable resource management and well-established institutional supports and brought to benefit climate resilience.

Table 3
Fixed Effects Regression Results

Variable	Coefficient	Std. Error	t-value
RainVar	−0.412***	0.091	−4.53
TempShock	−1.276***	0.334	−3.82
WaterUse	0.287***	0.063	4.56
SoilMgmt	8.914***	2.147	4.15
CSA	0.193**	0.081	2.38
InstQual	1.527**	0.642	2.38
Constant	67.34***	9.81	6.86

The model statistics in Table 4 shows that the empirical examination is grounded on balanced and sufficiently large panel information incorporating 420 observations in 28 countries with great cross-country and time variation in econometric estimation. This sample size improves the estimated coefficient reliability and can make significant inference on the determinants of agricultural productivity in the Global South.

This, within R^2 value of 0.63 indicates that the annual time-varying agricultural productivity in individual countries is (approximately) 63 per cent accounted for by climate, resource management, and institutional variables included. This reasonably good explanation value shows that the model identifies the important factors of dynamic in productivity especially the factors linked to climate stress and sustainable management of resources.

Also, the F -value of 18.92, which is statistically significant at the 1 percent level, verifies the overall joint significance of the explanatory variables. This finding suggests that the aggregate effect of the independent variables on agricultural productivity is statistically significant and that the model is well specified. Overall, these statistics prove that the estimated fixed effects model is sound empirically and appropriate to examine the outcomes of climate resilience and resource management in the Global South agriculture.

Table 4
Model Statistics

Statistic	Value
Observations	420
Countries	28
R^2 (within)	0.63
F-statistic	18.92***
Significance levels: *** p < 0.01, ** p < 0.05	

The empirical evidence of the interaction effects in the table is that the sustainable practices of resource management is a moderate that diminishes the negative effects caused by climate variability to agricultural productivity. The terms of all the interactions are positive and statistically significant, which means that the resilience of agricultural systems to climatic stress can be improved by the enhancement of resource management.

The relationship between variability of rainfall and efficient water use (RainVar X WaterUse) has a positive and significant value of 0.156 (Std. Error = 0.048). This finding suggests that elevated degree of efficiency in irrigation can offset the adverse consequences of rainfall variability significantly on crop production. Practically speaking, more water-efficient countries have less productivity lost during the times of unpredictable rainfall, which brings to the fore the significance of efficient irrigation systems in rescue right up to the normalizing precipitation regimes in agricultural production (Table 5).

In the same way, the coefficient of TempShock × SoilMgmt and the interaction of the two indicates the existence of a positive and statistically significant interaction between the two, i.e., 0.842 (Std. Error = 0.391). The implication of this finding is that, as the management of the soil is improved the agricultural productivity is less susceptible to increasing temperatures. Healthy soils make the soil moister, nutrient-filled, and root-resistant, which helps the crops with heat stress. The coefficient is quite large in terms of its size, which underscores the long-term resilience value of soil conservation as a climate adaptation measure.

The relationship between the variance of rainfall and the adoption of climate-smart agriculture (RainVar × CSA) is also positive and significant with a coefficient of 0.092 (Std. Error = 0.044). This finding suggests that increased asset rainfall variability has a moderate effect on the yields, which reduces with the increased adoption of climate-smart practices. Though the scale is less than that of water and soil management interactions, it indicates the compound aspect of climate-smart agriculture that is combined with several adaptation practices that together increase resilience.

In general, the results of the interaction prove that sustainable resource management is not only associated with the increased agricultural productivity, but the adverse effects of climate stressors are also significantly reduced. Such results strongly support empirical evidence to the policies that enhance integrated water management, soil conservation and climate-smart agricultural practices as measures to build climate-resilient agricultural systems in the Global South.

Table 5
Climate Stress × Resource Management Interaction

Variable	Coefficient	Std. Error
RainVar × WaterUse	0.156***	0.048
TempShock × SoilMgmt	0.842**	0.391
RainVar × CSA	0.092**	0.044

The dynamic panel estimation results in Table 6 reveal the stability of agricultural productivity and affirm the strength of the baseline results. The positive value of the coefficient on lagged agricultural productivity (Lagged Yield) is 0.612 and significant at 1% level. This shows that there is a high path dependent on agricultural output implying that nearly 61 percent of the current levels of output can be attributed to past levels of productivity. This outcome is an accumulation of the previous investments in agricultural infrastructure, adoption of technology, and management of resources practices and it highlights the long-term characteristics of agricultural resilience.

In the dynamic specification, the variable Rainfall variability (RainVar) still has a negative impact that is significant, with the coefficient of -0.371. This scale means that the variation of rainfall continues to lower agricultural productivity even after taking into consideration the level of productivity in the past. This finding is in line with the fixed effects estimates, which highlights the structural susceptibility of Global South agriculture to unpredictable precipitation patterns.

As previously stated, the coefficient of Efficient water use (WaterUse) is positive and very important with a 0.261 value. This observation implies that the productivity gains will be realized in the long run through enhancing efficiency in irrigation. A marginally reduced magnitude in relation to the static model demonstrates the converse nature of the dynamic specification and demonstrates that water management is a fundamental factor that leads to the long-term agricultural resilience. The use of climate-smart agriculture (CSA) also has a positive and statistically significant coefficient of 0.184, which implies that the more agricultural practices are adopted in the form of climate-smart, the greater the agricultural output in the long term. Despite a moderate effect size, the article demonstrates the accrued benefits of adaptive practices leading to resilience to climate stress when applied throughout the years.

On the whole, the System GMM findings support the conclusion that sustainable resource management and climate-smart practices are important in enhancing the resilience of agricultural practices in the Global South. These results offer significant evidence that policy interventions to achieve water efficiency and climate-smart agriculture can have long-term productivity effects despite rising climate variability through the consideration of dynamic adjustment and endogeneously.

Table 6
System GMM Results

Variable	Coefficient
Lagged Yield	0.612***
RainVar	–0.371***
WaterUse	0.261***
CSA	0.184**

According to the results of the diagnostic tests in Table 7, the estimates of the dynamic panel that were calculated using the System GMM approach are valid and reliable in a statistical way. The p-value of the Hansen test of over-identifying restrictions is 0.41, which is significantly larger than the standard significance levels. The result would mean that the null hypothesis of instrument validity is not rejected and that the instruments employed in the estimation are suitably taken and they are not associated with the error term. Thus, the model is not proliferated and mis-specified with instruments, and the estimated coefficients are supported.

On the same note, Arellano-Bond test of second order serial correlation [AR(2)], gives a p-value of 0.29, which shows no second-order autocorrelation of the differenced residuals. This finding validates the fact that the moment conditions that the System GMM estimator are based on hold and the dynamic specification is well-developed. When put together, the above diagnostic statistics reveal that the dynamic panel model is well specified, empirically robust, and can be used to make inference on the long-term impact of climate variability and sustainable management of the resources in agricultural productivity in the Global South.

Table 7
Diagnostics

Test	p-value
Hansen Test	0.41
AR(2)	0.29

Discussion and Policy Implications

Combined, the findings prove that climate variability is a major danger to agricultural systems in the Global South, but its negative impacts can be vastly countered by means of sustainable resource management. The more effective utilization of water, soil protection, and climate-responsible agriculture are suggested to be complementary measures that increase productivity and resilience.

The results underscore the significance of combined policy frameworks that initiate combinations between sustainable policy frameworks and climate adaptation. To further secure food security in the face of rising climate uncertainty, investments in efficiency of irrigation, the health of the soil, institutional capacity, and availability of climate resistant technologies to the farmer are necessary. Additionally, the adoption of sustainable practices can be speeded up by enhancing institutional quality and credit access, and their impacts of enhancing resilience will increase.

In a wider development way, the findings are consistent with the global sustainability agendas as it has identified the avenues in which the agricultural systems in the Global South can be able to shift to climate resilience without reducing productivity. Future studies can further inform this analysis using micro-level data, gender-disaggregated effects and region-specific ways of adapting as a way of refining policy interventions.

Conclusion

This paper has discussed the application of sustainable resource management in the creation of climate-resilient agricultural systems in the Global South in the context of a broad panel econometric model. The results have strong empirical support of the fact that climate variability, measured in terms of rainfall variability and temperature anomalies, can considerably diminish agricultural productivity. The findings of these studies corroborate the argument that Global South Agricultural systems are susceptible to escalating climatic stresses especially in areas where rain-fed agriculture is predominant and where there is a low adaptability.

Simultaneously, the analysis shows that the practice of sustainable resource management is critical in increasing agricultural resilience. The positive impacts of efficient water use, soil conservation methods, and the implementation of climate-smart agriculture are strong in their positive effect on crop yields. More to the point, the outcome of interaction indicates that these practices have a big effect on alleviating the negative effect of climate variants, where they have a buffering effect in the climate variability of rainfall and temperature shocks. The dynamic panel findings also indicate that the productivity increase due to investment in sustainable resource management is sustained over time, which strengthens the long-term character of the resilience-building processes.

Another very important enabling factor is also revealed through institutional quality, which focuses on the fact that governance, policy support and access to credit are critical in transforming sustainable practices into tangible productivity contributions. On the whole, the paper highlights that climate resilience in the agricultural sector cannot be attained by single interventions but should be integrated to embrace resource efficiency, adaptive technology and institutional fortification. The implications of these findings are vital in terms of policy implications of designing climate responsive agricultural plans in line with sustainable development goals in the Global South.

Future Perspectives

Although this study offers great cross-country information, there are still a few research points that can be followed in the future. To begin with, future research may use micro-level household or farm-level data to explain heterogeneity in adaptation behaviour, uptake of technologies and gender specific reaction to climate stress. This type of disaggregated analysis would provide more information on the social aspects of agricultural resilience and offer more context-specific policy interventions.

Second, introducing more environmental indicators into the analytical framework like soil carbon stocks, groundwater depletion, and biodiversity indicators would reinforce the knowledge of the ecological sustainability of agricultural systems. The incorporation of remote sensing with high resolution climate data may also enhance accuracy of climate- agriculture linkages.

Lastly, by examining agro-ecological zones of vulnerability in the Global South (i.e., drylands, mountainous areas, or coastal agriculture) as the central topic of the research, future studies could consider the region-specific resilience patterns. Such an extension would also be worthwhile, though, in the evaluation of the effectiveness of emerging technologies, digital agriculture, and mechanisms of climate finance in their ability to improve adaptive capacity. These contributions would lead to evidence-based policymaking towards achieving resilient, inclusive, and sustainable agricultural changes in the face of growing climatic change.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Informed consent for publication was obtained from all participants involved in the study.

Competing interests

Only one author is there therefore, no conflict of interest is there involved

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Author Contribution

Author AB conceptualized the study, designed the research framework, and led the overall manuscript preparation. He conducted the econometric analysis, interpreted the results, and drafted the major sections of the paper, including methodology, results, discussion, and conclusion. Author AS contributed to the theoretical framing and literature review, assisted in refining the research objectives, and provided critical inputs on policy implications and interpretation of findings. author AQ supported data compilation and variable construction, assisted in the empirical analysis, and contributed to the methodological refinement and robustness checks. Author AQ contributed to data organization, descriptive analysis, and preparation of tables and figures. He also assisted in reviewing and editing the manuscript for clarity and coherence and author IQ contributed to literature review, referencing, and formatting of the manuscript. She also assisted in proofreading and improving the overall presentation of the paper.

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Data Availability

The datasets analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

References

1. Abegunde VO, Sibanda M, Obi A. Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in South Africa. Int J Clim Change Strateg Manag. 2019;11(3):418–34. https://doi.org/10.1108/IJCCSM-01-2019-0002.
2. Altieri MA, Nicholls CI, Henao A, Lana MA. Agroecology and the design of climate change–resilient farming systems. Agron Sustain Dev. 2015;35(3):869–90. https://doi.org/10.1007/s13593-015-0285-2.
3. Aryal JP, Rahut DB, Maharjan S, Erenstein O. Climate risks and adaptation strategies of farmers in South Asia. Environ Dev. 2020;34:100399. https://doi.org/10.1016/j.envdev.2019.100399.
4. Bond S, Hoeffler A, Temple J. (2010). GMM estimation of empirical growth models. *CEPR Discussion Paper No. 3048*.
5. Brown ME, Antle JM, Backlund P, Carr ER, Easterling WE, Walsh MK, Tebaldi C. (2017). Climate change, global food security, and the U.S. food system. *USDA Technical Bulletin*, 1935.
6. Dell M, Jones BF, Olken BA. What do we learn from the weather? The new climate–economy literature. J Econ Lit. 2014;52(3):740–98. https://doi.org/10.1257/jel.52.3.740.
7. FAO. The state of food and agriculture 2021: Making agrifood systems more resilient to shocks and stresses. Food and Agriculture Organization of the United Nations; 2021.
8. IPCC. Climate change 2022: Impacts, adaptation and vulnerability. Cambridge University Press; 2022.
9. Kassie M, Teklewold H, Jaleta M, Marenya P, Erenstein O. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. Land Use Policy. 2015;42:400–11. https://doi.org/10.1016/j.landusepol.2014.08.016.
10. Lal R. Regenerative agriculture for food and climate. J Soil Water Conserv. 2020;75(5):A123–4.
11. Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Torquebiau E. Climate-smart agriculture for food security. Nat Clim Change. 2014;4(12):1068–72. https://doi.org/10.1038/nclimate2437.
12. Pretty J, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HCJ, Wratten S. Global assessment of agricultural system redesign for sustainable intensification. Nat Sustain. 2018;1(8):441–6. https://doi.org/10.1038/s41893-018-0114-0.
13. Rosegrant MW, Ringler C, Sulser TB, Ewing M, Palazzo A, Zhu T, Matthews N. Agriculture and food systems in a changing climate. Am J Agric Econ. 2020;102(2):400–15.
14. Wheeler T, von Braun J. Climate change impacts on global food security. Science. 2013;341(6145):508–13. https://doi.org/10.1126/science.1239402.