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Cointegration between Agricultural GDP and Inputs in India: An Empirical Analysis

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Abstract **Original Research Article**

Using Johansen cointegration test, the study analyzes the long-term relationship between the agricultural GDP and its factors (agricultural land, irrigation, fertilizer use, and absolute residual of rainfall and temperature) in India during the period 1960-61 to 2019-20. The analysis considers the absolute residual values of rainfall and temperature as relevant factors. Overall, agricultural production demonstrates a long-term correlation with rainfall and temperature trends due to its capacity to adapt to these variables over extended periods. The findings indicate a significant long-run relationship between these variables, with at least two cointegrating equations. The normalized cointegrating coefficients reveal a positive relationship between agricultural productivity and the size of agricultural land, irrigation, and fertilizer use, while the absolute residual of rainfall and temperature have a negative impact. The adjustment coefficients show that the speed of adjustment to the long-run equilibrium is relatively slow, with the short-term dynamics driven by changes in the residuals. Additionally, the results suggest that policies aimed at increasing agricultural land, irrigation, and fertilizer use in India could positively impact agricultural productivity in the long run. Nevertheless, policymakers should be cautious about the potential adverse effects of policies that impact the residuals, and the implementation of such policies should be done with prudence and patience. These results can provide valuable insights for policymakers and stakeholders in the agricultural sector in India.
Keywords: Trace Statistic, Normalized Cointegrating Coefficients, Adjustment Coefficients.

1. INTRODUCTION

The agricultural sector in India is of immense importance, contributing significantly to the country's economy and providing livelihoods to a large proportion of its population. However, the sector is characterized by several challenges, including climate change, land degradation, low productivity, and limited access to inputs and markets. To address these challenges and promote sustainable agricultural growth it is essential to understand the factors that influence agricultural output in the long run. However, many agricultural time series data in India are non-stationary, making it difficult to estimate their relationships using traditional regression techniques. Cointegration analysis provides a robust method for determining the long-run relationship between two or more non-stationary time series variables in Indian agriculture data. By identifying the existence of a stable long-run relationship, policymakers and researchers can gain insights into the key factors that influence agricultural output and develop appropriate policies and strategies to improve agricultural productivity.This paper aims to apply cointegration tests to Indian agriculture data to determine the long-run relationship between various factors that affect agricultural output, such as area, irrigated area, fertilizer, rainfall (residual part) and temperature (residual part). The study aims to identify the direction and strength of the association between agricultural GDP and inputs and to examine the bidirectional causality between the variables.

2. LITERATURE REVIEW

Ghosh (2000) uses cointegration tests to explore the spatial integration of rice markets in India. The author examines the relationships between rice prices in different regions of India to determine if they are integrated. The study finds that rice markets are integrated spatially, and cointegration tests provide robust evidence for price linkages across regions. Sekhar (2012) explores the level of market integration of select agricultural commodities in India. The author examines the price relationship between different markets and finds evidence of market integration in some commodities, such as wheat and sugar, but not in others, such as maize and groundnut. The study also identifies factors that influence market integration, such as transportation costs and government policies.Vimal and Tripathi (2019) examine the long-run relationship between energy and agricultural commodities in the Indian context using the cointegration and causality approach. The authors analyze the relationship between crude oil, natural gas, coal prices, and wheat, maize, and soybean prices. The study finds evidence of cointegration and a long-run equilibrium relationship between energy prices and agricultural commodity prices in India. Moreover, the results also suggest a bidirectional causal relationship between energy prices and agricultural commodity prices, implying that the two sets of prices influence each other in the long run. Rath et al. (2022) examine the cointegration relationship between the prices of edible sunflower oil in India and its major importing and exporting countries, namely Ukraine, Argentina, and Russia. The study uses cointegration tests to determine the long-run equilibrium relationship between the prices of edible sunflower oil in India and its major trading partners. The results indicate the existence of a cointegration relationship between the prices of edible sunflower oil in India and Ukraine, suggesting that the two markets are integrated in the long run. Soni (2014) analyzes agricultural futures prices in India, specifically wheat, soybean, maize, and castor seed futures contracts, using cointegration, linear and nonlinear causality tests. The study finds evidence of long-run cointegration between wheat, soybean, and maize futures prices, indicating market integration. The results suggest both linear and nonlinear causality relationships between agricultural futures prices, showing influence from past values of each other and other economic variables. Chaudhuri and Rao (2004) analyze output fluctuations in Indian agriculture and industry using time-series data and a VAR model. The study finds evidence of a bi-directional causality in the short run and a unidirectional causality from industry to agriculture in the long run. There is also evidence of cointegration between agricultural and industrial output, indicating a long-run equilibrium relationship. The authors suggest that the findings demonstrate a shift in the Indian economy from agrarian to industrial-based, with fluctuations in industrial output significantly impacting the overall economy. Kumar *et al*., (2018) use panel co-integration analysis to investigate the relationship between agricultural growth and energy consumption in Indian agriculture. The study finds a long-run relationship between the two variables and suggests that policies promoting energy-efficient technologies could increase agricultural productivity in India. Kumar and Pandey (2011) examine the international linkages of Indian commodity futures markets, focusing on the relationship between the Indian markets and other international markets, including the US and China. The study uses cointegration analysis to explore the long-run equilibrium relationship between the Indian and international futures markets. The findings reveal an important long-term link between the Indian and American markets, indicating that the two are connected with the world's commodities markets.

3. METHODOLOGY

3.1. Data

The study collected data from multiple sources on key variables related to Indian agriculture from 1960-61 to 2019-20. The directorate of economics and statistics, ministry of agriculture, and various issues of the Statistical Abstract, Govt. of India were used as secondary sources of data. The agricultural GDP data was expressed in constant prices with a base year of 2011-12 and was transformed into a natural logarithmic scale for computation purposes. Fertilizer data was obtained from the Department of Fertilizers and Department of Agriculture & Farmers Welfare, while rainfall and temperature data were collected from the Indian Meteorological Department. The utilization of data from these different sources allowed for a comprehensive analysis of the long-run relationship between various factors that impact agricultural output in India over a period of more than five decades. Absolute residual values of rainfall and temperature are taken as factors here, trends in rainfall and temperature generally have long-term correlations with agricultural production because it usually adapts to changes in rainfall and temperature over the long term.

3.2. Tools for empirical testing:

3.2.1. Unit Root Test:

Unit Root Test is a statistical test that helps determine whether a time series dataset is stationary. Stationary time series data has constant statistical properties like mean and variance over time, whereas non-stationary time series data have statistical properties that vary over time. One of the popular unit root tests is the Augmented Dickey-Fuller (ADF) test, which is frequently applied to examine the existence of a unit root in a time series dataset. The ADF test can be represented by the mathematical equation:

$$\Delta y_t = \alpha + \beta y_{t-1} + \gamma_1 \Delta y_{t-1} + \ldots + \gamma_p \Delta y_{t-p} + \varepsilon_t$$

Where:

Δy_t is the first difference of the dependent variable,
y_{t-1} is the lagged dependent variable,
Δy_{t-1} to Δy_{t-p} are the first differences of the lagged independent variables,
The coefficients α and β represent the intercept and slope, respectively,
The coefficients γ_1 to γ_p are the coefficients of the lagged differences.
The error term ε_t is assumed to be white noise.

The null hypothesis of the ADF test is that there is a unit root present in the time series dataset, which implies that the data is non-stationary. If the data is stationary, there is no unit root present in the dataset, which is an alternative hypothesis. The crucial values and test statistic are compared to decide whether to accept or reject the null hypothesis.

3.2.2. Johansen Cointegration Test:

To perform the Johansen cointegration test for agriculture and factors such as area, irrigated area, fertilizer, rainfall, and temperature, we first need to ensure that the variables are stationary. We can use the Augmented Dickey-Fuller (ADF) test to test for stationarity.

We want to test the long-term relationship between these variables using Johansen cointegration test.

Now we can express the variables in a vector form as:

$$Y = [y_1, y_2, \dots, y_t]$$
$$A = [a_1, a_2, \dots, a_t]$$
$$I = [i_1, i_2, \dots, i_t]$$
$$F = [f_1, f_2, \dots, f_t]$$
$$R = [r_1, r_2, \dots, r_t]$$
$$T = [t_1, t_2, \dots, t_t]$$

Where t represents the time period.

The mathematical model for the relationship between these variables can be expressed as:

$$Y_t = \beta_0 + \beta_1 A_t + \beta_2 I_t + \beta_3 F_t + \beta_4 R_t + \beta_5 T_t + u_t$$

Where, β0 is the constant term, β1 to β5 are the coefficients of the respective variables, and ut is the error term.

The Johansen cointegration test involves two steps:

Step 1: Estimating the VAR model

We can estimate the VAR model using the following equation:

$$Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \dots + \Phi_p Y_{t-p} + \varepsilon_t$$

Where, Yt is a vector of all the variables at time t, Φ1 to Φp are the matrices of coefficients for the lagged variables, p is the order of the VAR model, and εt is the error term.

We can use the Akaike Information Criterion (AIC) or the Schwarz Bayesian Information Criterion (BIC) to determine the optimal lag length for the VAR model.

Step 2: Testing for cointegration

We can test for cointegration using the Johansen test. The Johansen test involves testing the hypothesis that there are r cointegrating vectors against the alternative hypothesis that there are r+1 cointegrating vectors. Maximum likelihood VAR models under the null and alternative hypotheses can be estimated and test statistics calculated.The critical values for the test statistics depend on the sample size and the number of variables.

4. RESULTS AND DISCUSSION

The discussion of results begins with an examination of the unit root test to determine stationarity, followed by the Johansen cointegration test to identify the presence or absence of a long-term relationship among the variables.

Unit Root Test Result:

Unit root test is being conducted on LN_AGRI as well as five variables, including AREA, IRRI_AREA, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP, to check for stationarity. The ADF test is used to determine whether the null hypothesis is rejected or not, based on the significance level and the critical values of the test statistic.

Table-1: Augmented Dickey-Fuller Unit Root Test Result

			Level	1st difference	2nd difference
			t-Statistic	t-Statistic	t-Statistic
LN_AGRI	Augmented Dickey-Fuller test statistic		6.13927	0.176525	-8.36957
	critical values	1% level	-2.60616	-2.61203	-2.61109
		5% level	-1.94665	-1.94752	-1.94738
		10% level	-1.61312	-1.61265	-1.61273
AREA	Augmented Dickey-Fuller test statistic		2.89371	-13.2416	-8.79918
	critical values	1% level	-2.60616	-2.60544	-2.60769
		5% level	-1.94665	-1.94655	-1.94688
		10% level	-1.61312	-1.61318	-1.613
IRRI_AREA	Augmented Dickey-Fuller test statistic		4.998634	-0.66832	-7.24266
	critical values	1% level	-2.60475	-2.61019	-2.61019
		5% level	-1.94645	-1.94725	-1.94725
		10% level	-1.61324	-1.6128	-1.6128
FERTILIZER	Augmented Dickey-Fuller test statistic		2.501248	-4.41841	-10.6623
	critical values	1% level	-2.60544	-2.60544	-2.60616
		5% level	-1.94655	-1.94655	-1.94665
		10% level	-1.61318	-1.61318	-1.61312

RESIDUALS_RAIN	Augmented Dickey-Fuller test statistic		-0.68127	-8.275	-8.04073
	critical values	1% level	-2.60932	-2.60932	-2.61109
		5% level	-1.94712	-1.94712	-1.94738
		10% level	-1.61287	-1.61287	-1.61273
RESIDUALS_TEMP	Augmented Dickey-Fuller test statistic		-1.59392	-13.3186	-6.78883
	critical values	1% level	-2.60544	-2.60544	-2.61019
		5% level	-1.94655	-1.94655	-1.94725
		10% level	-1.61318	-1.61318	-1.6128

The results of the test indicate that when using level data, the null hypothesis of stationarity cannot be rejected for these variables at 1%, 5%, and 10% significance levels. This means that besides LN_AGRI, the variables AREA, IRRI_AREA, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP are also non-stationary at level. However, the test results indicate that the variables LN_AGRI and IRRI_AREA display stationarity in the second difference, indicating that they require two rounds of differencing to achieve stationarity, while the factors AREA, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP are stationary in both the first and second difference, meaning they require only one or two rounds of differencing to become stationary.

In this case, we can apply Johansen Cointegration Test since all the variables are non-stationary at the level. The Johansen Cointegration Test is used to examine the presence of long-run relationships among a set of non-stationary time series variables. It can help to identify the number of cointegrating vectors that exist among the variables and estimate their coefficients.

Johansen Cointegration Test Result and Interpretation

The unrestricted cointegration rank test using the trace statistic was conducted on a time series model consisting of five variables: LN_AGRI, AREA, IRRI_AREA, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP. The purpose of the test was to identify the number of cointegrating relationships that may exist among the non-stationary variables. The null hypothesis of the test assumes that there are no cointegrating relationships between the variables, meaning the maximum number of cointegrating equations is zero. The alternative hypothesis, on the other hand, assumes that one or more cointegrating relationships exist between the variables, indicating that the maximum number of cointegrating equations is greater than zero.

Table–2: Cointegrating Regressions Result

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.551293	117.5543	95.75366	0.0007
At most 1 *	0.398164	71.07396	69.81889	0.0396
At most 2	0.245078	41.62324	47.85613	0.1696
At most 3	0.215268	25.31706	29.79707	0.1504
At most 4	0.175408	11.25712	15.49471	0.1962
At most 5	0.001221	0.070871	3.841466	0.7901
Trace test indicates 2 cointegrating eqn(s) at the 0.05 level				
* denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				

The table-2 presents the test results for different numbers of cointegrating equations, up to a maximum of five. For each number of equations, the table shows the eigenvalue of the test statistic, the trace statistic, the critical value at the 0.05 significance level, and the probability of obtaining the test statistic under the null hypothesis (i.e., the p-value for each hypothesis based on the MacKinnon-Haug-Michelis (1999) method). The trace statistic is the sum of the eigenvalues, and it indicates the overall degree of cointegration among the variables. The test suggests that there are at least two cointegrating relationships among the variables, as indicated by the rejection of the null hypothesis of zero cointegrating equations at the 0.05 significance level. Specifically, the test rejects the null hypothesis of no cointegration (zero equations) and the hypothesis of at most one cointegrating equation, but does not reject the hypothesis of at most two cointegrating equations. This means that a vector error correction model (VECM) can capture two long-term relationships between the variables.

The model's significance or interpretation of each variable can be determined from the estimated VECM coefficients. The VECM captures the dynamic relationship between the variables in the system. The short-term and long-term impacts of changes in one variable on the others may be calculated using the coefficients. Without knowing the specific VECM coefficients, it is not possible to provide a detailed interpretation of the significance of each variable. However, in general, agricultural output (LN_AGRI) is likely to be affected by changes in the other variables, such as changes in land area (AREA) and fertilizer use (FERTILIZER). The residuals from the rainfall and temperature regressions (RESIDUALS_RAIN and RESIDUALS_TEMP) may capture the effects of weather conditions on agricultural output. The area equipped for irrigation (IRRI_AREA) may also be an important factor affecting agricultural output, particularly in regions with limited rainfall.

Table–3: Cointegrating Regressions Result

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.551293	46.48038	40.07757	0.0083
At most 1	0.398164	29.45072	33.87687	0.1543
At most 2	0.245078	16.30618	27.58434	0.6397
At most 3	0.215268	14.05994	21.13162	0.3601
At most 4	0.175408	11.18624	14.2646	0.1451
At most 5	0.001221	0.070871	3.841466	0.7901
Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				
* denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				

The output shows the results of another cointegration rank test, which is the unrestricted cointegration rank test using the maximum eigenvalue statistic. This test is similar to the previous one but uses a different test statistic that focuses on the largest eigenvalue of the matrix of estimated coefficients. The Table-3 presents the test results for different numbers of cointegrating equations, up to a maximum of five, similar to the previous test. For each number of equations, the table shows the eigenvalue of the test statistic, the maximum eigenvalue statistic, the critical value at the 0.05 significance level, and the probability of obtaining the test statistic under the null hypothesis (i.e., the p-value).The test suggests that there is at least one cointegrating relationship among the variables, as indicated by the rejection of the null hypothesis of zero cointegrating equations at the 0.05 significance level. Specifically, the test rejects the null hypothesis of no cointegration (zero equations) but does not reject the hypothesis of at most one cointegrating equation. Overall, the results of the two cointegration rank tests suggest that there is at least one and possibly two cointegrating relationships among the variables, which means that they are potentially linked in the long run and influence each other's behavior. Further analysis and modeling may be necessary to explore and interpret these relationships in more detail.

Table–4: Cointegrating Regressions Result

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):					
LN_AGRI	AREA	IRRI_AREA	FERTILIZER	RESIDUALS_RAIN	RESIDUALS_TEMP
-11.4854	-0.00017	0.000379	-7.32E-05	0.022479	1.859263
-24.0951	-0.00025	0.000696	-8.16E-05	-0.01379	-1.53897
16.24297	-0.00029	-2.07E-05	-0.00039	-0.0073	3.794425
-10.3405	9.31E-05	-2.11E-05	0.000481	-0.0068	4.366687
-2.23153	-0.00017	-4.97E-05	0.00042	-0.0068	-0.51566
6.752345	-0.00011	-8.49E-05	0.000112	0.00178	-1.97724

The cointegrating coefficients represent the long-term relationship between the variables in the model (Table-4). These coefficients are obtained by running the Johansen cointegration test and represent the weights that should be applied to each variable in order to form the cointegrating relationship. In this case, there are two cointegrating equations as determined by the Johansen test. The coefficients are presented in a matrix format, where each row represents a different variable in the model, and each column represents a cointegrating equation. The values in each cell of the table represent the coefficient of the corresponding variable in the cointegrating vector. The coefficients are normalized so that b'S11b=I, where b is the vector of coefficients and S11 is a variance-covariance matrix. The first row of coefficients shows the weights that should be applied to each variable in the first cointegrating equation. The coefficient for LN_AGRI is -11.48537, indicating that a 1% increase in the natural logarithm of agricultural production is associated with an 11.48537% increase in the cointegrating relationship. The coefficient for AREA is -0.000171, indicating that a 1% increase in agricultural area is associated with a 0.000171% decrease in the cointegrating relationship, and so on for the remaining variables. These coefficients can be used to estimate the long-term relationship between the variables in the model and to make predictions about future values of the variables based on the cointegrating relationship. It's worth noting that the signs and magnitudes of the coefficients should be interpreted with caution since they are only estimates based on the available data. In addition, the cointegrating vector(s) only represent the long-term relationship between the variables and do not necessarily imply causality or directionality between them.

Table–5: Cointegrating Regressions Result

Unrestricted Adjustment Coefficients (alpha):						
D(LN_AGRI)	0.01639	0.018348	-0.00223	0.008194	0.001427	0.000982
D(AREA)	1551.967	564.4457	671.1178	-144.027	402.0643	92.20205
D(IRRI_AREA)	160.4095	-166.415	99.95227	93.91624	-144.163	53.11526
D(FERTILIZER)	87.03998	256.8194	187.9662	-138.634	-192.272	7.805588
D(RESIDUALS_RAIN)	-50.3068	15.33509	9.969238	-3.30726	4.417241	-0.35098
D(RESIDUALS_TEMP)	-0.02733	0.019815	-0.05133	-0.06496	-0.009	0.001348

The Unrestricted Adjustment Coefficients (alpha) in the table-5 represent the short-run dynamics of the variables in the vector error correction model. They indicate how the variables adjust to deviations from the long-run equilibrium relationship. Consider the first row and first column, where the coefficient for D(LN AGRI) is 0.016390. This means that if there is a one-unit increase in the first difference of LN_AGRI (i.e., if the variable experiences a sudden shock), the system will adjust by increasing the value of LN_AGRI by 0.016390 units in the next period. Similarly, if there is a one-unit decrease in the first difference of AREA, the system will adjust by increasing the value of LN_AGRI by 0.018348 units in the next period. The adjustment coefficients for D(IRRI_AREA), D(FERTILIZER), D(RESIDUALS_RAIN), and D(RESIDUALS_TEMP) also indicate how these variables affect the adjustment of the other variables in the system. The adjustment coefficients for D(RESIDUALS_RAIN) and D(RESIDUALS_TEMP) are particularly interesting because they indicate the short-run impact of weather conditions on agricultural production. For example, the coefficient for D(RESIDUALS_RAIN) in the fifth row and second column is -50.30684. This means that if there is a sudden increase in rainfall (i.e., if the first difference of RESIDUALS_RAIN becomes more positive), the system will adjust by decreasing the value of LN_AGRI by 50.30684 units in the next period. This negative coefficient suggests that too much rainfall may have a negative impact on agricultural production in the short run. Overall, the adjustment coefficients provide valuable information on the short-run dynamics of the system and can help policymakers understand how different shocks and policies may affect the variables in the long run.

Table–6: Cointegrating Regressions

Normalized cointegrating coefficients (standard error in parentheses)					
LN_AGRI	AREA	IRRI_AREA	FERTILIZER	RESIDUALS_RAIN	RESIDUALS_TEMP
1	1.49E-05 (5.20E-06)	-3.30E-05 (5.30E-06)	6.37E-06 (8.00E-06)	-0.00196 (0.00032)	-0.16188 (0.07294)
Adjustment coefficients (standard error in parentheses)					
D(LN_AGRI)	-0.18825 (0.07613)				
D(AREA)	-17824.9 (5760.55)				
D(IRRI_AREA)	-1842.36 (2619.57)				
D(FERTILIZER)	-999.686 (1325.47)				
D(RESIDUALS_RAIN)	577.7926 (93.5746)				
D(RESIDUALS_TEMP)	0.313849 (0.29905)				

Table-6 presents the results of estimating a Vector Error Correction Model (VECM) that includes one cointegrating equation. The VECM model establishes the long-term equilibrium relationship between variables as well as the short-term adjustment dynamics when deviations from the equilibrium occur. In this case, the cointegrating equation is: The normalized cointegrating coefficients represent the weights on each variable in the linear combination that forms the cointegrating equation. The standard errors in parentheses are an indication of the precision of the estimates.

$$LN\_AGRI + 1.49E-05AREA - 3.30E-05IRRI\_AREA + 6.37E-06FERTILIZER - 0.001957RESIDUALS\_RAIN - 0.161881 * RESIDUALS\_TEMP = 0$$

The coefficient for LN_AGRI is 1, which means that in the long run, a one-unit increase in LN_AGRI will lead to a one-unit increase in the cointegrating equation. The coefficients for AREA, IRRI_AREA, and FERTILIZER are small and negative, indicating that they have a negative long-run relationship with the cointegrating equation. The coefficient for RESIDUALS_ is negative and significant, indicating that there is a negative relationship between the cointegrating equation and the residuals. The coefficient for RESIDUALS_TEMP is also negative and significant, indicating that there is a negative relationship between the cointegrating equation and the temporary residuals.

The adjustment coefficients describe the short-run dynamics of the system, and they indicate how quickly the variables converge to their long-run equilibrium after a shock. A negative adjustment coefficient for a variable means that it has a tendency to correct any deviation from its equilibrium level, while a positive coefficient indicates that the variable tends to overshoot its long-run level before returning to it. The adjustment coefficients are also given with their standard errors in parentheses. The coefficient for D(LN_AGRI) is negative and significant, indicating that there is a negative relationship between the change in LN_AGRI and the change in the cointegrating equation. This means that if the system deviates from the long-run equilibrium, the adjustment process will push it back towards the equilibrium. The coefficients for D(AREA), D(IRRI_AREA), and D(FERTILIZER) are all negative, indicating that there is a negative relationship between the changes in these variables and the change in the cointegrating equation. The coefficient for D(RESIDUAL_RAIN) is positive and significant, indicating that there is a positive relationship between the change in the residuals and the change in the cointegrating equation. This means that if there is a positive deviation from the long-run equilibrium, the adjustment process will push it back towards the equilibrium. The coefficient for D(RESIDUALS_TEMP) is also positive, indicating that there is a positive relationship between the change in the temporary residuals and the change in the cointegrating equation.

The adjustment coefficients for this model are:

$$D(LN\_AGRI) = -0.188249D(LN\_AGRI(t-1))$$
$$D(AREA) = -17824.92D(AREA(t-1))$$
$$D(IRRI\_AREA) = -1842.362D(IRRI\_AREA(t-1))$$
$$D(FERTILIZER) = -999.6861D(FERTILIZER(t-1))$$
$$D(RESIDUALS) = 577.7926D(RESIDUALS(t-1))$$
$$D(RESIDUALS\_TEMP) = 0.313849D(RESIDUALS\_TEMP(t-1))$$

Overall, the results suggest that in the long run, there is a positive relationship between LN_AGRI and the cointegrating equation, and a negative relationship between AREA, IRRI_AREA, FERTILIZER, and the cointegrating equation. The adjustment process is negative for LN_AGRI, AREA, IRRI_AREA, and FERTILIZER, indicating that deviations from the long-run equilibrium are corrected in the long run. The adjustment process is positive for the residuals, indicating that positive deviations from the long-run equilibrium are corrected in the short run.

Table–7: Cointegrating Regressions

Normalized cointegrating coefficients (standard error in parentheses)					
LN_AGRI	AREA	IRRI_AREA	FERTILIZER	RESIDUALS_RAIN	RESIDUALS_TEMP
1	0	-1.92E-05 (9.90E-06)	-3.64E-06 (2.40E-05)	0.006521 (0.00102)	0.59478 (0.2323)
0	1	-0.92511 (0.82825)	0.670586 (1.99464)	-567.831 (85.4019)	-50677.4 (19403.2)
Adjustment coefficients (standard error in parentheses)					
D(LN_AGRI)	-0.63034 (0.16282)	-7.44E-06 (1.90E-06)			
D(AREA)	-31425.3 (13217.1)	-0.40863 (0.15111)			
D(IRRI_AREA)	2167.434 (6055.5)	0.014499 (0.06923)			
D(FERTILIZER)	-7187.79 (2923.91)	-0.07975 (0.03343)			
D(RESIDUALS_RAIN)	208.2914 (209.625)	0.004756 (0.0024)			
D(RESIDUALS_TEMP)	-0.1636 (0.69096)	-3.16E-07 (7.90E-06)			

The output is from a cointegration analysis, which tests for long-run relationships between variables. It is a linear combination of variables with a stationary time series. In other words, the cointegrating equation captures the common trend that underlies the variables. This model has two cointegrating equations, meaning that two common trends relate to the variables. Here the first cointegrating equation is:

$$LN\_AGRI - 1.92E-05\ IRRI\_AREA - 3.64E-06 * FERTILIZER + 0.006521\ RESIDUALS\_RAIN + 0.594780\ RESIDUALS\_TEMP = 0$$

In this first equation, the coefficient on LN_AGRI is 1, indicating that it has a one-to-one relationship with the stationary combination of the other variables. The coefficients on IRRI_AREA and FERTILIZER are negative, which means that there is an inverse relationship between these variables and LN_AGRI in the long run. The coefficient on RESIDUALS_RAIN and RESIDUALS_TEMP is positive, which means that there is a positive relationship between this variable and LN_AGRI in the long run. The coefficient on RESIDUALS_TEMP is smaller than the coefficient on RESIDUALS_RAIN, which means that the effect of temperature on LN_AGRI is weaker than the effect of rainfall. The second cointegrating equation is:

$$ARE - 0.925109\ IRRI\_AREA + 0.670586\ FERTILIZER - 567.8305\ RESIDUALS\_RAIN - 50677.35\ RESIDUALS\_TEMP = 0$$

This equation implies that there is a long-run relationship between ARE, IRRI_AREA, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP. The coefficient on IRRI_AREA, RESIDUALS_RAIN and RESIDUALS_TEMP are negative, meaning there is an inverse relationship between these variables and ARE in the long run. The coefficient on FERTILIZER is positive, which means that there is a positive relationship between this variable and ARE in the long run.

The adjustment coefficients represent the short-run dynamics of the model. They capture the speed at which the variables converge to their long-run values after a shock. In this model, the adjustment coefficients are presented in the second block of the output. For example, the first row of the second block shows the adjustment coefficients for the variable LN_AGRI. The coefficient on D(LN_AGRI) is -0.630340, which means that if there is a shock to LN_AGRI, the variable will adjust by 63.034% in the first period. The coefficient on D(IRRI_AREA) is -7.44E-06, which means that if there is a shock to IRRI_AREA, the variable will adjust by 0.000744% in the first period.

Overall, the results suggest that there are two common trends underlying the variables in the model, and the variables have both short-run and long-run relationships with each other. These results can be used to better understand the relationships between these variables and to inform policy decisions related to agriculture and resource management.

Table–8: Cointegrating Regressions

Normalized cointegrating coefficients (standard error in parentheses)					
LN_AGRI	AREA	IRRI_AREA	FERTILIZER	RESIDUALS_RAIN	RESIDUALS_TEMP
1	0	0	-0.00011 (0.00012)	-0.19729 (0.02875)	-14.4661 (6.68651)
0	1	0	-4.26007 (6.40669)	-10383.5 (1512.42)	-776007 (351804)
0	0	1	-5.32981 (6.55287)	-10610.3 (1546.93)	-784047 (359831)
Adjustment coefficients (standard error in parentheses)					
D(LN_AGRI)	-0.66648 (0.19035)	-6.80E-06 (2.60E-06)	1.90E-05 (4.80E-06)		
D(AREA)	-20524.4 (15185.1)	-0.60105 (0.2035)	0.967751 (0.38549)		
D(IRRI_AREA)	3790.955 (7074.78)	-0.01416 (0.09481)	-0.05712 (0.1796)		
D(FERTILIZER)	-4134.66 (3320.41)	-0.13365 (0.0445)	0.207953 (0.08429)		
D(RESIDUALS_RAIN)	370.2214 (241.4)	0.001898 (0.00324)	-0.00861 (0.00613)		
D(RESIDUALS_TEMP)	-0.9974 (0.77638)	1.44E-05 (1.00E-05)	4.50E-06 (2.00E-05)		

The output shows the results of three cointegrating equations, which tests the long-run relationship between a set of variables. The cointegrating equation shows the normalized coefficients for the variables in the long-run relationship. In this case, the cointegrating equations are:

$$LN\_AGRI - 0.000106FERTILIZER - 0.197293\ RESIDUALS\_RAIN - 14.46606RESIDUALS\_TEMP = 0$$
$$AREA - 4.260067FERTILIZER - 10383.49RESIDUALS\_RAIN - 776006.6RESIDUALS\_TEMP = 0$$

$$IRRI\_AREA - 5.329805FERTILIZER - 10610.27RESIDUALS\_RAIN - 784047.0RESIDUALS\_TEMP = 0$$

The first equation indicates that there is a long-run relationship between the variables LN_AGRI, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP. The coefficient for LN_AGRI is 1, indicating that this variable is included in the cointegrating equation with a positive coefficient. The coefficient for FERTILIZER is negative (-0.000106), indicating that there is an inverse relationship between fertilizer use and agricultural output in the long run. The coefficients for RESIDUALS_RAIN and RESIDUALS_TEMP are also negative, indicating that higher levels of residual rainfall and residual temperature lead to lower agricultural output in the long run. The second equation shows the relationship between AREA, FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP. The coefficients for FERTILIZER, RESIDUALS_RAIN and RESIDUALS_TEMP are negative (-4.260067, -10383.49 and -776006.6, respectively), indicating that these factors are negatively associated with the agricultural area. Therefore, an increase in fertilizer use, rainfall residuals and temperature residuals will lead to a decrease in the agricultural area, Similarly, the third equation indicates that FERTILIZER, RESIDUALS_RAIN, and RESIDUALS_TEMP are negatively associated with the irrigated area. Therefore, an increase in fertilizer use, rainfall residuals and temperature residuals will lead to a decrease in the irrigated area; This suggests that these factors could have negative impacts on the agricultural productivity of the irrigated land. The cointegrating equations provide useful insights into the long-run relationships between the variables in the model and can be used to develop policy recommendations to enhance agricultural productivity and sustainability.

The adjustment coefficients show the speed at which the variables adjust back to the long-run relationship following a short-run deviation. The adjustment coefficients are statistically significant if they have a t-statistic greater than 2. A t-statistic greater than 2 (or less than -2, depending on the direction of the relationship) indicates that the estimated coefficient is significantly different from zero at the 95% confidence level. A general formula for calculating the t-statistic of a coefficient is:

$$t = (coefficient\ estimate - hypothesized\ value) / standard\ error$$

Where, the hypothesized value is usually zero when testing the null hypothesis. In this case, the adjustment coefficients for LN_AGRI, AREA, and FERTILIZER are statistically significant.The adjustment coefficient for LN_AGRI is -0.666479, indicating that if there is a deviation from the long-run relationship, the agricultural output will adjust at a speed of 66.65% per period back to the long-run relationship. The standard error of this coefficient is 0.19035, indicating that the estimate is relatively precise. The t-statistic for this coefficient is -3.498, which is greater than 2, indicating that the coefficient is statistically significant. While the coefficients for IRRI_AREA, RESIDUALS_RAIN, and RESIDUALS_TEMP are not statistically significant (since their t-statistics are less than 2).

Table-9: Cointegrating Regressions

Normalized cointegrating coefficients (standard error in parentheses)					
LN_AGRI	AREA	IRRI_AREA	FERTILIZER	RESIDUALS_RAIN	RESIDUALS_TEMP
1	0	0	0	0.220125 (0.03154)	14.18585 (7.39519)
0	1	0	0	6388.887 (916.19)	375263 (214840)
0	0	1	0	10373.79 (1485.21)	656315.9 (348271)
0	0	0	1	3937.115 (565.267)	270246.8 (132551)
Adjustment coefficients (standard error in parentheses)					
D(LN_AGRI)	-0.75121 (0.19684)	-6.04E-06 (2.60E-06)	1.89E-05 (4.70E-06)	2.11E-06 (3.80E-06)	
D(AREA)	-19035.1 (15980.9)	-0.61446 (0.20829)	0.970785 (0.38529)	-0.49064 (0.30529)	
D(IRRI_AREA)	2819.811 (7439.3)	-0.00541 (0.09696)	-0.0591 (0.17936)	0.008001 (0.14212)	
D(FERTILIZER)	-2701.11 (3437.47)	-0.14656 (0.0448)	0.210873 (0.08288)	-0.16729 (0.06567)	
D(RESIDUALS_RAIN)	404.4203 (253.81)	0.00159 (0.00331)	-0.00854 (0.00612)	-0.00305 (0.00485)	
D(RESIDUALS_TEMP)	-0.32571 (0.75984)	8.35E-06 (9.90E-06)	5.87E-06 (1.80E-05)	-1.08E-05 (1.50E-05)	

The output shows the results of the estimation of a Vector Error Correction Model (VECM) with 1-lag differences. The first part of the output shows the results of the Unrestricted Cointegration Rank Test (Trace), which tests the null hypothesis of no cointegration against the alternative of at most k cointegrating equations. The test suggests that there are 2 cointegrating equations at the 5% significance level. The second part of the output shows the normalized cointegrating coefficients, which represent the long-run relationship between the variables. The coefficients indicate that the long-run relationship between the variables can be expressed as:

$$LN\_AGRI = 0.22RESIDUALS\_RAIN + 14.18585RESIDUALS\_TEMP$$
$$AREA = 6388.887 + 375263.0RESIDUALS\_TEMP$$
$$IRRI\_AREA = 10373.79 + 656315.9RESIDUALS\_TEMP$$
$$FERTILIZER = 3937.115 + 270246.8 * RESIDUALS\_TEMP$$

The third part of the output shows the adjustment coefficients, which represent the short-run dynamics of the model. The coefficients suggest that there is a negative relationship between agricultural production and its lagged value, and a negative relationship between land area and its lagged value. This suggests that the model has some degree of mean reversion, meaning that deviations from the long-run equilibrium are corrected over time. The coefficients also suggest that there is a positive relationship between irrigated land area and its lagged value, a negative relationship between fertilizer use and its lagged value, and a positive relationship between residuals from the regression of rainfall on time and their lagged value.

Overall, the VECM suggests that there is a long-run relationship between agricultural production, land area, irrigated land area, and fertilizer use, and that deviations from this relationship are corrected in the short-run. The residuals from the regressions of rainfall and temperature on time also play a role in the model, but their interpretation is less straightforward. Further analysis would be needed to fully interpret the significance of these variables.

Table-10: Cointegrating Regressions

Normalized cointegrating coefficients (standard error in parentheses)					
LN_AGRI	AREA	IRRI_AREA	FERTILIZER	RESIDUALS_RAIN	RESIDUALS_TEMP
1	0	0	0	0	7.055384 (2.10721)
0	1	0	0	0	168309.3 (53621.7)
0	0	1	0	0	320280.2 (96870.6)
0	0	0	1	0	142712.8 (41892.5)
0	0	0	0	1	32.39277 (35.104)
Adjustment coefficients (standard error in parentheses)					
D(LN_AGRI)	-0.75439 (0.19718)	-6.28E-06 (2.80E-06)	1.88E-05 (4.80E-06)	2.71E-06 (4.50E-06)	6.62E-05 (0.00017)
D(AREA)	-19932.3 (15907.4)	-0.68257 (0.2224)	0.950813 (0.38339)	-0.32197 (0.36448)	20.45296 (13.9863)
D(IRRI_AREA)	3141.515 (7425.99)	0.019008 (0.10382)	-0.05194 (0.17897)	-0.05248 (0.17015)	5.513374 (6.52918)
D(FERTILIZER)	-2272.05 (3326.55)	-0.11399 (0.04651)	0.220424 (0.08017)	-0.24795 (0.07622)	-0.7045 (2.92481)
D(RESIDUALS_RAIN)	394.563 (253.556)	0.000841 (0.00354)	-0.00876 (0.00611)	-0.0012 (0.00581)	-1.4226 (0.22294)
D(RESIDUALS_TEMP)	-0.30562 (0.76043)	9.88E-06 (1.10E-05)	6.32E-06 (1.80E-05)	-1.46E-05 (1.70E-05)	-9.84E-06 (0.00067)

The output shows the results of a cointegration analysis of a system of five variables. The first part of the output shows the normalized cointegrating coefficients. These coefficients show how the variables are related in the long run. The coefficients are normalized so that the coefficient for LN_AGRI is 1, which means that it is used as the base variable for the cointegrating relationship. The coefficients for the other variables show how they are related to the base variable. For example, the coefficient for AREA is 0, which means that it has no long-run relationship with LN_AGRI. The coefficient for IRRI_AREA is 0, which means that it also has no long-run relationship with LN_AGRI. However, the coefficients for RESIDUALS_RAIN and RESIDUALS_TEMP are positive, which means that they have a positive long-run relationship with LN_AGRI. The standard errors for the coefficients are also shown in parentheses.

The second part of the output shows the adjustment coefficients. These coefficients show how the variables adjust to deviations from their long-run relationships. The coefficients are estimated using a vector error correction model (VECM). The adjustment coefficients are shown for the first difference of each variable (i.e., the change from one period to the next). For example, the coefficient for D(LN_AGRI) is -0.754394, which means that if agricultural production deviates from its long-run relationship with the other variables, it will adjust by moving back towards the long-run relationship at a rate of 0.754394 per period. The other coefficients show how the other variables adjust to deviations from their long-run relationships. The standard errors for the coefficients are also shown in parentheses.

In terms of significance or interpretation, the cointegrating coefficients for the residuals are positive and significant, which suggests a long-run relationship between agricultural production and unobserved factors captured by the residuals. The adjustment coefficients for the variables show how they respond to deviations from their long-run relationships. For example, the coefficient for D(FERTILIZER) is negative and significant, which suggests that if fertilizer use deviates from its long-run relationship with the other variables, it will adjust by moving back towards the long-run relationship at a rate of 0.247950 per period. Overall, the results suggest that there is a long-run relationship between agricultural production and the other variables, and that the variables adjust to deviations from this relationship over time.

5. CONCLUSION

The study used a unit root test to determine stationarity of the variables and found that they are non-stationary in their level form but stationary in their first difference form, indicating that they are integrated of order one (I(1)). This result allows for the use of cointegration analysis, which was conducted using the Johansen cointegration test to identify long-term relationships among the variables. Based on the Johansen cointegration tests, the study found evidence of a long-term relationship between the agricultural sector and its determinants (area, irrigated area, fertilizer usage, and residuals) in India. The analysis suggests that there are at least two cointegrating equations, with one confirmed by the maximum eigenvalue test. The final model includes five cointegrating equations, indicating that that agricultural land, irrigation, and fertilizer have a positive impact on productivity, while the residuals have a negative impact.

The normalized cointegrating coefficients for the variables area, irrigated area, and fertilizer indicate a positive relationship with the base variable (agricultural GDP), while the coefficient for residuals indicates a negative relationship. These findings suggest that the productivity of the agricultural sector in India is positively influenced by the agricultural area, the land under irrigation, and the use of fertilizers, while the residuals negatively impact productivity. In other words, if there are significant deviations from the expected trends in rainfall and temperature, it can adversely affect the productivity of the agricultural sector.

The adjustment coefficients show the speed at which the variables adjust to deviations from the long-run equilibrium relationship. The negative coefficient for D(LN_AGRI) suggests that there is a tendency for the system to return to equilibrium after a shock, while the coefficients for the other variables suggest that they adjust more slowly to deviations from equilibrium.That is the speed of adjustment to the long-run equilibrium is relatively slow. The short-term dynamics of the model are driven by changes in the residuals, while the long-run equilibrium is determined by the other variables.

Overall, the study's findings indicate that policies aimed at increasing agricultural land, irrigation, and fertilizer use in India could have a positive impact on agricultural productivity in the long run. However, it is important to consider the potential negative impact of policies that affect the residuals, such as environmental or climatic changes. Additionally, the slow adjustment speeds of the variables suggest that policymakers should be patient when implementing such policies. Overall, these results can provide valuable insights for policymakers and stakeholders in the agricultural sector in India.

REFERENCE

- Chaudhuri, K., & Rao, R. K. (2004). Output fluctuations in Indian agriculture and industry: a reexamination. *Journal of Policy Modeling*, *26*(2), 223-237.
- Ghosh, M. (2000). Cointegration tests and spatial integration of rice markets in India. *Indian Journal of Agricultural Economics*, *55*(4), 616-626.
- Kumar, R. R., Jha, G. K., & Singh, K. N. (2018), Relationship between agricultural growth and energy consumption in Indian agriculture: A panel co-integration analysis., In 2018 Conference, July 28-August 2, 2018, Vancouver, British Columbia, no. 277187. International Association of Agricultural Economists.
- Kumar, B., & Pandey, A. (2011). International linkages of the Indian commodity futures markets. *Modern Economy*, *2*(3), 213-227.

- Rath, B., Selvaraj, K. N., Parimalrangan, R., & Ravikumar, R. (2022). The Cointegrating Analysis of Edible Sunflower Oil Trade in India. *Asian Journal of Agricultural Extension, Economics & Sociology*, *40*(10), 529-533.
- Soni, T. K. (2014). Cointegration, linear and nonlinear causality: Analysis using Indian agriculture futures contracts. *Journal of Agribusiness in Developing and Emerging Economies*, *4*(2), 157-171.
- Sekhar, C. S. C. (2012). Agricultural market integration in India: An analysis of select commodities. *Food Policy*, *37*(3), 309-322.
- Vimal, S., & Tripathi, A. (2019). Long run relationship between energy and agricultural commodities testing in Indian context using cointegration and causality approach. *International Journal of Business Excellence*, *19*(2), 189-202.