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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Pattern of Agricultural Progress in India's North-East and the Contributing Factors: An Econometric Analysis

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Abstract

Despite being blessed with rich agro-climatic conditions, the largest agrarian state in India's North-East, Assam recorded relatively poor agricultural growth, since independence. The question of agricultural performance in terms of use of factors and growth pattern always arise that seems to vary in different stages of policy shift. Agricultural diversity increased in the initial phase with the expansion of agricultural area but slowed down in the later stages. However, the nature of agricultural diversity and use of resources including land allocations reflects the adaptation of farming community, absorption of labour force and sustainability of earning of farmers. The objectives are to analyze: i) the pattern of agricultural growth, diversity; ii) relative contribution of crop diversification, yield and area towards output growth in the pre-Green Revolution, Green Revolution and Post-Reform period; iii) association of various factors with crop yields in the short run and the adjustment process in the long run. Using secondary data, semi-log linear and spline regression functions we examined the growth and stationarity of growth processes is checked by ADF test. Times series analyses like cointegration and ARDL bound testing approach has been followed to examine the relation of various factors with yield of various crops in the short and long run. The ECM also provides the process of adjustment and CUSUM(Q) test is used for checking fitness of the models. Changes in diversity are analyzed through Herfindahl Index and the additive decomposition technique is employed to examine changing contribution of growth of yield, area and cropping pattern and their interactions. The result reveals varied impacts of main weather variable (rainfall), technological factors and cropping intensity on the yields of crops in different phases since 1950-51. Area effect on output and cropping pattern growth though declined, yield growth contributed increasingly in successive sub-periods in Assam. However, the contribution of modern technology towards the growth has not been uniform in the three major stages of agricultural transformation in Assam.

Keywords: Agricultural growth, Diversity, Agro-technology, Stationarity, Cointegration, ARDL Bound Test, North-East India.

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1. Introduction

1.1 Background

Agricultural progress is crucial for the economic development of several developing countries. Besides providing food, agriculture absorbs large labour force, thus provide income and employment to the rural masses. Development of agriculture in a region depends on agro-climatic specifications, socio-economic conditions of people, technical and institutional factors of that area. Existence of wide regional diversities and variations of the factors ultimately lead to uneven agricultural development across the region or country. Though the seed-water-fertilizer package (Green Revolution) was introduced in the mid-1960s to achieve self-sufficiency in food grains production, it was mainly confined to Punjab, Haryana and Western Uttar Pradesh. The Green Revolution technology gradually spread over the eastern parts of India during 1980s and the pace of adoption in North-East India has been very slow.

Assam is the largest agrarian state in North-East India, with varied agro-climatic endowments and agricultural diversity. Thus, varieties of food, non-food as well as horticultural crops are produced in this region depending upon the availability of various inputs, infrastructure and agro-implements. There are three distinct paddy growing seasons in the state viz., autumn, winter and summer paddy. Among these three seasonal varieties, winter paddy occupies the dominant position followed by summer paddy. Mustard is the most important non-food crop cultivated in winter. Also, maize, millets, tea, sugarcane, arecanut, banana are grown. Though over 70 percent of population of Assam relies on agriculture for livelihood, its contribution to Gross State Domestic Product (GSDP) has declined from 57.24 per cent in 1970-71 to 15.64 per cent in 2019-20 (Directorate of Economics and Statistics, Assam).

The state has not yet shown noticeable growth in use of modern technology in agriculture. About 47 per cent of area under paddy is covered by high yielding varieties (HYV) and merely about six per cent of gross area under cultivation (GCA) is covered by irrigation. Thus cropping intensity is pegged at low level (147.81 per cent). Per hectare fertilizer consumption is around 70 kg (Statistical Handbook of Assam, 2020).

A comparison with all India picture helps us to understand the prevailing agricultural status of Assam. While all India average cropping intensity increased from only 112 per cent in 1951-54 to 152 per cent in 2017-20; in Assam it increased from 106 per cent to 148 per cent during that period. Irrigation intensity at all India level increased from merely 17 per cent to about 50 per cent during last seven decades, in Assam still 6.43 per cent of GCA is covered under irrigation during 2017-20, although there are numerous Himalayan rivers and tributaries. It shows the underdeveloped status of irrigation prevailing in Assam. The rising cropping intensity whatever possible indicates that much of its increased area is without irrigation and at the mercy of rainfall. In terms of fertilizer consumption Assam was above all-India average with figures respectively 0.71 and 0.69 Kg per hectare in 1951-54, it increased to 70.34 Kg per hectare in Assam in comparison to phenomenal increase at all India level to 130.26 Kg per hectare in 2017-20. Also, coverage of HYV seeds in Assam is 47.53 per cent of GCA as against 57.49 per cent of all India average during 2017-20 (Govt. of India, Website: eands.dacnet.nic.in).

1.2 Objective

Agricultural growth is necessary not only for attaining high overall growth but also to address poverty. Understanding its nature of growth and contributing factors would help us to understand various issues related to agricultural growth and its change over time. Also, analysis of the nature of cropping pattern changes helps us to understand the nature of agricultural development and contribution of crop diversity towards agricultural growth. With this view in mind, this paper examines the growth of major crops (area, production and yield) and the use of various inputs associated with the production process.

Understanding the process of agricultural growth and application of factor inputs and technology would help in designing agricultural activities not only in India but also in other parts of the world depending on the regional agro-climatic conditions and available technical factors. Thus, the outcome of this paper would be of immense help in policy making for the farming community despite varied regional conditions.

The rest of the paper is organized as follows. In the next section a detailed review of literature is presented, which is followed by data and methodology and then the results with a detailed discussion. Finally, it ends up with concluding remarks.

1.3 Studies on Agricultural Development, Crop Diversity and Roles of Various Factors

Plethora of studies on agricultural development, crop diversity and the contributing factors are there and the relevant studies are reviewed here. Significant growth of area, production and yield of major crops in different parts of India over time has been observed in the studies of Bhalla and Singh (1997); Kalamkar, Atkare and Shende (2002). In general, variability of production has been more than the variability in area and yield during 1949-50 to 1997-98. High growths in production of foodgrains, cotton and sugarcane in the second half of 20th century were mainly due to yield effect. Contribution of growing cultivated area was seen for tur and oilseeds and area-yield interaction effect was recorded for wheat. Subrahmanyam and Sekhar (2003) found the annual growth of agriculture (total factor productivity) in Andhra Pradesh to be 3.5 per cent during 1955-56 to 1975-76 and it decelerated afterwards due to inadequate irrigation, changing agro-climatic conditions, limited investment in agricultural research. However, fertilizer application was recorded to be very high. Agriculture in Assam has also been subject to wide spatio-temporal variation with a slow process of adaptation and diversification to changing climate (De and Bodosa, 2015), but concentration of a few crops has been observed in case of West Bengal after 1980 due to commercialization and technological expansion (De and Chattopadhyay, 2010).

Although the economy of India has undergone structural transformation over time, with declining share of agriculture in GDP, dependence of rural workforce on agriculture for employment has not declined (Singh, 2010). Thus, pressure on agriculture is mounting to raise farmers' income. Changing cropping pattern revealed that after green revolution cultivation has been inclined to some high value non-food crops. The result of state-level analysis by Bhalla and Singh (2011) showed outstanding progress of labour productivity in the reform period with the adoption of new technology. It was however confined only to the irrigated areas. Diversification in favour of high value crops was observed, but during the post-reform period deceleration in rate of growth happened primarily for the decline in investment in irrigation or management of water resources. In some regions, it was due to decreasing input use efficiency and weather uncertainties (De, 2003). Like studies in other regions (De, 2000; De and Chattopadhyay, 2010; De and Bodosa, 2015), Kumar and Singh (2014) noted deceleration in area and production of sugarcane is observed in the state of Haryana, though yield growth was positive.

The decomposition analysis revealed that high growth rate in agriculture was due to cropping pattern shift towards high value crops (fruits, horticultural crops) and rising yield in Gujarat during 1990-2010 (Pattnaik and Shah, 2015). Crops exhibiting higher growth also show greater variability in yield and price. But the price effect of individual crops has increased over time with reduced yield effect. Price-area, price-yield interactions were stronger during 2000s as compared to 1990s. Substantial price increase is associated with favorable variation of area and yield during the 2000s when price effect was more important than the yield effect.

Zhai et al. (2017) examined the relationship among yield of wheat, use of machine, area under cultivation of wheat, fertilizer used, precipitation and temperature in Henan Province in China during 1970 to 2014. ARDL model was employed to test the influence of climatic factors as well as technical factors on yield of wheat in the long run. The climatic factors were found to have weak impacts on yield of wheat, while technical progress was primarily responsible for increasing yield of wheat. In the same way, Jena (2021) using Panel Autoregressive Distributed Lag (PARDL) model in selected districts of Odisha found adverse impacts of rising temperature and rainfall on the production of crops, which was similar to the findings of Chandio et al. (2019), and Guntukula and Goyari (2020). Using regression analysis, Reddy and Dutta (2018) found that pesticides, rainfall, electricity and use of HYV seeds have statistically significant impact on agricultural GDP but the impacts of fertilizer and net irrigated area were insignificant. Paria et al. (2021) revealed that greater irrigation facilities, diversified crop basket, use of more chemical fertilizers and higher yield positively affect cropping intensity. Moreover, rainfall variations and share of GSDP in agriculture have no significant impact on increasing cropping intensity.

2. Materials and Methods

2.1. Description of Data

The study is confined to the selected major crops (Paddy, Wheat, Tur, Mustard, Jute, Potato and Sugarcane) of Assam. The chosen crops are widely grown in the state and these crops together shares about 75 per cent of the total area under cultivation thus promp us to use for the purpose of analysis. Also, the selection of these crops is based on the availability of continuous data for the period 1951-52 to 2019-20. The entire study period is divided into three sub-periods. Period I: Pre-Green Revolution (1951-54 to 1968-71), Period II: Green Revolution (1971-74 to 1988-91), and Period III: Economic Reforms (1991-94 to 2017-20). Although Green Revolution in India started in mid-1960s, it reached Assam in 1970s and very slowly. Thus, 1971 is considered here as the initial year of Green Revolution period in Assam. The decade of 1990s is well known for a series of economic reforms, including liberalization of agricultural market have taken place. The reasons to study those sub-periods are to examine if there has been any substantial change with the change in regime and economic policy adopted in the country and comparison of results of these sub-periods would provide an insight into the changes in sources of agricultural growth across different sub-periods.

The study is based on secondary data. Time series data on area, production and yield of the above-mentioned crops, gross cropped area (GCA), and rainfall are collected from Directorate of Economics and Statistics (DES), Government of Assam, Agriculture and Cooperation Department of Government of India for the period 1951-52 to 2019-20. Data on irrigation were available in the office of Chief Engineer, Irrigation Department of Assam since 1981-82. Area under high yielding varieties of crops in Assam was available since 1981-82 and that on fertilizer use was available from 1961-62 to 2019-20.

2.2 Methodology

Semi-log regression model is run to estimate the exponential growth rate of area, production, and yield. The regression equation used is $\text{Log } Y_t = \alpha + \beta t$ (Eq. 1),

where, Y_t represents value of dependent variable (area, production, or yield) at time 't', t is the time in year and α, β are the two parameters. Here, β is the annual exponential rate of growth of Y.

Besides, Poirier (1973) linear spline regression (Johnston, 1972) is employed to capture the trend effects of different periods. Considering linear trend, the regression equation for three different sub-periods assuming different slopes may be written as

$Y_t = \alpha_1 + \beta_1 t + u_t$ for $t \leq a$ (Eq. 2), where a = (1971-72)

$Y_t = \alpha_2 + \beta_2 t + u_t$ for $a < t \leq b$ (Eq. 3), where b = (1991-92)

$Y_t = \alpha_3 + \beta_3 t + u_t$ for $b < t$ (Eq. 4)

Combining all these equations (2, 3 and 4) with $\text{Ln}Y_t$, as dependent variable, it can be estimated together as

$\text{Ln } Y_t = \alpha_1 + \delta_1 D_{1t} + \delta_2 D_{2t} + \delta_3 D_{3t} + u_t$ (Eq. 5)

Where, $D_{1t} = t$ (for the period from 1951-52 till 1970-71)

$D_{2t} = 0$ for $t \leq a$ $D_{2t} = t - a$ for $a \leq t \leq b$ (for the period from 1971-72 to 1990-91)

$D_{3t} = 0$ for $t \leq a$ $D_{3t} = t - b$ for $a \leq t \leq b$ (for the period from 1991-92 to 2019-20)

Comparing equation set (2), (3) and (4) with equation (5), we find

$\beta_1 = \delta_1$

$\beta_2 = \delta_1 + \delta_2$ and

$\beta_3 = \delta_1 + \delta_2 + \delta_3$, which are nothing but the trend coefficients of the respective sub-periods.

After establishing the sub-period growth rates of area, production, and yield of selected crops all the variables have been checked for stationarity by using Augmented Dickey Fuller (Unit Root) Test with Schwarz Info Criterion (SIC) including intercept and time trend. It is checked for both the level and first difference form (Dickey and Fuller, 1979, 1981). Some of the variables are found to be stationary, which means integrated of order zero and others are integrated of order one. The test is done by using the following equation:

$\Delta Y_{it} = \alpha_i + \beta_i.t + \gamma_{i0} Y_{it-1} + \sum_j \delta_{ij} \Delta Y_{i,\, t-j} + \varepsilon_{it}$ (Eq. 6).

Here, Y_{it} is the value of respective dependent variable at time t. The inference is drawn based on the usual Dickey–Fuller τ- statistic of γ_{i0}, which has a non-standard distribution.

2.3 ARDL Model

Growth and diversity of agricultural crops is a continuous process influenced by several factors such as the use of physical inputs, irrigation, weather condition, market, access to credit, institutional and infrastructure development. Analyzing the effect of relevant variables within a simple framework is difficult as these variables affect crop output through various mechanisms. However, an attempt has been made to analyze the impact of irrigation, rainfall, chemical fertilizer and cropping intensity on output of the selected crops by estimating Autoregressive Distributed Lag (ARDL) model also known as bound testing cointegration technique as developed by Pesaran and Shin (1999), Pesaran et al. (2001). Since variables under consideration here are found to have different order of integration, ARDL model has been employed. Besides, it generates both the short run and long run coefficients simultaneously and follows the usual OLS procedure for cointegration among variables. Accordingly, the following general form of ARDL model with n lags for variable Y and m lag for variable X is specified as

$$Y_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{i=1}^{m} \beta_i X_{t-i} + U_t \quad \text{(Eq. 7)}$$

Whereas the general form of ARDL error correction model is as follows:

$$\Delta Y_t = \alpha_0 + \sum \beta_j Y_{t-i} + \sum \beta_j X_{t-j} + \varphi ECM_{t-i} + \varepsilon_t \quad \text{(Eq. 8)}$$

In the above equation, φ shows the speed of adjustment parameter and for significant ECM model φ must be negative. Error Correction Term specifies the short run adjustment of variables towards the long-run equilibrium. ECM_{t-1} is the residuals that are acquired from the estimated cointegration model.

The implicit relationship of yield of crop with variables is specified as follows:

Yield = f(Cultivated Area, Rainfall, Fertilizer Consumption, Irrigation, Cropping Intensity) (Eq. 9)

Here, irrigation and fertilizers capture the influence of technology, rainfall stands for changing climatic condition (significant proportion of cultivated area depend upon rainfall and its variation affects crop output substantially). Similarly, proxy for land (area under cultivation) is captured by cropping intensity as net sown area remains more or less constant over the years. This linear combination is transformed into log-linear model which would present suitable and proficient outcomes as compared to the simple linear model.

$$LnY_{it} = \beta_{i0} + \beta_{i1} LnA_{it} + \beta_{i2} LnRAIN_t + \beta_{i3} LnFER_t + \beta_{i4} LnIRRI_t + \beta_{i5} LnCI_t + \mu_{it} \quad \text{(Eq. 10)}$$

Where, Y_{it} represents the yield of i^{th} agricultural crop, A_{it} represents area under i^{th} crop, while $RAIN_t$, FER_t, $IRRI_t$ and CRI_t represent rainfall, consumption of fertilizer, irrigation and cropping intensity respectively.

The ARDL model has two steps for estimation. In the first step, we examine the presence of a long-run relationship between the agricultural crops and study inputs by using the model.

$$\Delta LnY_{it} = \alpha_0 + \sum_{j=1}^{p} \alpha_{1ij} \Delta LnY_{it-k} + \sum_{j=1}^{p} \alpha_{2ij} \Delta LnA_{it-k} + \sum_{j=1}^{p} \alpha_{3ij} \Delta LnRAIN_{t-k} + \sum_{j=1}^{p} \alpha_{4ij} \Delta LnFER_{t-k} + \sum_{j=1}^{p} \alpha_{5ij} \Delta LnIRRI_{t-k} + \sum_{j=1}^{p} \alpha_{6ij} \Delta LnCI_{t-k} + \beta_{1i} LnY_{it-1} + \beta_{2i} LnA_{it-1} + \beta_{3i} LnRAIN_{t-1} + \beta_{4i} LnFER_{t-1} + \beta_{5i} LnIRRI_{t-1} + \beta_{6i} LnCI_{t-1} + \varepsilon_{it} \quad \text{(Eq. 11)}$$

In the second step, we estimate the short-run relation among the study variables using the error Correction Model (ECM), which is written as

$$\Delta LnY_{it} = \alpha_0 + \sum_{j=1}^{p} \alpha_{1ij} \Delta LnY_{it-k} + \sum_{j=1}^{p} \alpha_{2ij} \Delta LnA_{it-k} + \sum_{j=1}^{p} \alpha_{3ij} \Delta LnRAIN_{t-k} + \sum_{j=1}^{p} \alpha_{4ij} \Delta LnFER_{t-k} + \sum_{j=1}^{p} \alpha_{5ij} \Delta LnIRRI_{t-k} + \sum_{j=1}^{p} \alpha_{6ij} \Delta LnCI_{t-k} + \varphi ECM_{it-1} + \varepsilon_{it} \quad \text{(Eq. 12)}$$

2.4 Bound Testing Procedure

In ARDL Bound testing, long-run relationship among the variables is checked. At first, cointegration among the variables is checked. The null hypothesis that H_0: $\beta_{ji} = 0$, for all j = 1, 2, …, 6 indicates the absence of any cointegration among yield, area under crop, rainfall, consumption of fertilizer, irrigation and cropping intensity.

Wald F-statistic is used to check the significance of lagged levels of the variables in a conditional unrestricted equilibrium error correction model. The test includes the F-test of the joint significance of the coefficient of lagged variables to verify that there is a long-term relation among the variables. Pesaran et al. (2001) has provided one upper and a lower critical value for testing. If the computed value of F-statistic is greater than upper critical bound, then the H_0 is rejected, and the variables are considered to be co-integrated. On the other hand, if the value of F-statistic is lower than the lower critical bound (LCB), then the variables are not co-integrated. However, if value of F-statistic falls within the lower and upper critical values band then inference of inconclusive test is drawn. Akaike Information Criterion (AIC) is used for appropriate lag selection. At this stage, the long run elasticities β_{1i}, β_{2i}, β_{3i}, β_{4i}, β_{5i}, and β_{6i} are obtained.

2.5 CUSUM and CUSUMQ Test

After confirming long-run relationship among the variables, we incorporate cumulative sum (CUSUM) and cumulative sum of squares (CUSUMQ) tests (Brown et al., 1975). These tests are used to check the goodness of fit for ARDL model as suggested by Pesaran et al. (2001) to incorporate the residuals of the error correction model and the results are presented in graphical form. For existence of the stability the plot of CUSUM and CUSUMQ have to lie within the 5% critical band.

2.6 Diversification of Crop and its Contribution to Agricultural Growth

For simplicity and its wide application, Herfindahl Index (HI) of diversification is used for measuring crop diversity and its variation over time. Mathematically, the index $HI = \sum(P_i)^2$ (Eq. 13) where, P_i represents acreage proportion of i^{th} crop in total cropped area. The value of the index ranges between 0 and 1 and a higher value of HI implies less diversification i.e., more concentration and vice-versa. On the other hand, the Simpson Index (SI) measures the extent of diversity and is written as $SI = 1 - \sum p_i^{\,2}$, where p_i represents proportion of area under i^{th} crop to GCA. A zero value means that the total cultivated area is dedicated to a single crop (perfect specialization) and if the area is evenly distributed among all the crops (i.e., maximum diversification), it approaches to one.

The additive decomposition of agricultural growth (Minhas and Vaidyanathan, 1965) has been used to examine the relative contribution of area, yield, cropping pattern and their interactions to total change in output. It has been worked out as follows:

Changes in output during a period $\Delta Q = Q_t - Q_0 = A_t \sum C_{it} Y_{it} P_{i0} - A_0 \sum C_{i0} Y_{i0} P_{i0,}$

$$= (A_t - A_0) \sum C_{i0} Y_{i0} P_{i0} + A_0 \sum C_{i0} (Y_{it} - Y_{i0}) P_{i0} + A_0 \sum (C_{it} - C_{i0}) Y_{i0} P_{i0} + (A_t - A_0) \sum (C_{it} - C_{i0}) Y_{i0} P_{i0}$$

$$+ (A_t - A_0) \sum C_{i0} (Y_{it} - Y_{i0}) P_{i0} + A_0 \sum (C_{it} - C_{i0})(Y_{it} - Y_{i0}) P_{i0} + (A_t - A_0) \sum (C_{it} - C_{i0})(Y_{it} - Y_{i0}) P_{i0} \quad \text{(Eq. 14)}$$

Where, Q_0 and Q_t represent total value of agricultural output at constant price (P_{i0}) of the region in the base and final period respectively. A_0 and A_t are GCA in the base and final period respectively. $C_{i0} = (A_{i0}/A_0)$ and $C_{it} = (A_{it}/A_0)$ are respectively the proportion of area under i^{th} crop to GCA in the base and final period and Y_{it} and Y_{i0} represent yield of i^{th} crop in the base and final period, P_{io} is the harvest price of i^{th} crop in the base period (here 1951-52). On the right-hand side of equation (14), the first three components represent direct effects of area, yield and cropping pattern, which means the change in output due to variation of single factor only keeping the other two factors constant. The next three components are the interaction effects of area-cropping pattern, area-yield, and cropping pattern-yield. The last one is the interaction of all i.e., area, yield and cropping pattern.

3. Results and Discussion

3.1 Agricultural Growth

Substantial growth in area and production of major crops has been recorded during the first two sub-periods i.e., 1951-54 to 1970-73 and 1971-74 to 1990-93. Whereas, during the reform period (1991-94 to 2017-20), a significant diversity towards a few crops has been observed (*Table 1*). Yield of major crops also grew faster during the Green Revolution period and that continued in the third period, excepting wheat, tur, jute and sugarcane. Growth rate of area and production of autumn paddy have been positive but decelerated in the later period and became negative during Period III. Although positive area and production growth rate of autumn paddy was not associated with yield growth (which was negative) in the Period I, its yield attained accelerated growth in periods

II and III. Increase in production of winter paddy during Periods I and II was due to the expansion of cultivated area. However, during period III growth rate of production declined despite acceleration in yield growth. Production growth rate of summer paddy was the highest at 11.62 per cent annual exponential rate during Period I, which decelerated in Period II and increased further during Period III. Increase in production was the result of increase in area and yield of summer paddy during all the sub-periods.

Table 1. Annual Exponential Rate of Growth of Area, Production and Yield of Major Crops in Assam (1951-54 to 2017-20) (per cent)

	Area			***Production***			***Yield***		
Crops	*Period I*	*Period II*	*Period III*	*Period I*	*Period II*	*Period III*	*Period I*	*Period II*	*Period III*
Autumn Paddy	2.52***	0.41*	-5.74***	1.98***	0.88	-3.72***	-0.53	0.47	2.14***
Winter Paddy	0.90***	1.07***	0.31***	0.97***	2.18***	1.96***	0.07	1.10***	1.64***
Summer Paddy	11.51***	4.27***	4.45***	11.62***	4.46***	6.92***	0.10	0.18	2.36***
Total Paddy	1.36***	0.98***	-0.16*	1.23***	2.03***	2.06***	-0.13	1.04***	2.23***
Wheat	9.08***	5.28***	-6.29***	8.90***	4.69***	-5.98***	-0.17	-0.56*	0.33
Tur	0.89	3.10***	-0.68***	3.05***	2.92***	0.43**	2.14**	-0.18	1.11***
Rape & Mustard	0.98***	5.50***	-0.13	0.64	6.38***	0.96**	-0.33	0.83*	1.10***
Jute	0.30***	-1.28***	-1.19***	0.45	-0.13	-0.45	0.15	1.16**	0.75***
Potato	1.97***	5.39***	1.78***	0.35	8.56***	1.46***	-1.58	3.00***	-0.31
Sugarcane	1.44***	0.61	-0.62**	3.68***	11.31***	-0.77**	2.21***	10.63***	-0.15

Note: ***, ** and * indicates significant level of 1%, 5% and 10% respectively

Growth rate of production of wheat was significantly positive during Periods I and II, which however became significantly negative during Period III. Area of wheat also followed a similar pattern; yield growth has been insignificant throughout the study periods. Growth rates of area and production of tur has declined during the period III though it was positive in the initial years and the yield growth rate declined continuously till the Period III. Production of mustard also saw accelerated growth from first to second sub-period and declined again during Period III. The increase in production in earlier Green Revolution period was due to growth of area under cultivation, which was however negative during Period III. The yield growth however followed a continuous upward trend. Jute and sugarcane saw declining trend in area and production with the progress of agriculture despite some increase in its yield. The growth rate of production for potato was positive over all the periods, alongside the area and yield, particularly in Periods II and III.

Table 2. Annual Exponential Rate of Growth during different Sub-periods Obtained from the Estimation of Spline Function (per cent)

	Area			***Production***			***Yield***		
Crops	*Period I*	*Period II*	*Period III*	*Period I*	*Period II*	*Period III*	*Period I*	*Period II*	*Period III*
Autumn Paddy	2.56***	-1.72***	-8.14***	2.66 ***	-1.81***	-6.10***	0.09	-0.09	2.22***
Winter Paddy	0.92***	0.29***	-0.62***	1.58***	0.30	0.51	0.66***	0.01	1.14***
Summer Paddy	9.44***	-4.20***	-4.93***	10.63***	-4.83***	-3.61***	1.08***	-0.66	1.39***
Total Paddy	1.34***	-0.13	-1.52***	1.89***	-0.13	0.32	0.54***	-0.01	1.87***
Wheat	12.35***	1.89	-17.23***	14.21***	2.25***	-18.37***	1.66***	0.35	-1.39**
Tur	2.77***	2.18***	-3.33***	3.01***	2.35***	-2.87***	0.23	0.18	0.47
Rape & Mustard	2.52***	1.36***	-2.12***	2.86***	1.65**	-1.23**	0.33**	0.29	0.91**
Jute	-1.04***	0.49	-0.48	-0.40*	0.36	-0.20	0.65***	-0.13	0.28
Potato	3.31***	-0.10	-0.96***	5.03***	-0.21**	-2.15**	1.67***	-0.11	-1.20*
Sugarcane	0.73***	2.00***	-1.77**	8.20***	-3.55***	-6.73***	7.41***	-5.44***	-5.05***

Note: ***, ** and * indicates significant level of 1%, 5% and 10% respectively

During Period I, stable and positive production growth rate of major crops was mainly due to increase in area for all the crops except for tur and sugarcane (*Table 1*). It may be noted that during Period I there was very little modernization of agriculture in Assam, as reflected from inadequate usage of fertilizer, negligible irrigation and lack of technological innovation. Area growth continued to be positive during Period II except for jute. However, increase in area growth rate was more in case of tur, mustard and potato, which indicates accelerated pace of diversification for non-food crops during that period. Growth rates of production were also observed to be positive and stable for most of the crops and yield growth also improved except for wheat and tur. Period II, the phase of

Green Revolution in Assam, recorded faster growth of yield with the gradual adoption of modern techniques. During Period III, growth rates of area and production were negative for most of the crops, as land size was inelastic and land use for other purposes also grew. But positive growth of yields of most of the crops has been recorded for the growing usage of fertilizer, irrigation and certain modern implements. Summer paddy also managed to maintain a significant positive growth throughout the periods.

Table 3. Unit Root Test for Stationarity of Log of Area and Yield of Major Crops, Rainfall, Irrigation, Fertilizer and Cropping Intensity during 1951 to 2019

Variable	*Level*	*First Difference*	*Order of Integration*	*Variable*	*Level*	*First Difference*	*Order of Integration*
LnAAP	2.82 (1.00)	-10.16 (0.00)	I(1)	LnYAP	-2.01 (0.5833)	-8.70 (0.00)	I(1)
LnAWP	-1.80 (0.695)	-11.52 (0.00)	I(1)	LnYWP	-3.96 (0.0148)	-12.55 (0.0001)	I(0)
LnASP	-2.86 (0.177)	-8.78 (0.00)	I(1)	LnYSP	-3.37 (0.0662)	-10.24 (0.00)	I(0)
LnATP	-1.16 (0.910)	-10.09 (0.00)	I(1)	LnYTP	-1.71 (0.7364)	-5.07 (0.0006)	I(1)
LnAWT	0.30 (0.998)	-8.00 (0.00)	I(1)	LnYWT	-3.73 (0.0269)	-9.90 (0.00)	I(0)
LnATR	-1.65 (0.763)	-9.50 (0.00)	I(1)	LnYTR	-6.01 (0.00)	-9.52 (0.00)	I(0)
LnARM	-0.947 (0.944)	-7.765 (0.00)	I(1)	LnYRM	-5.49 (0.0001)	-12.14 (0.00)	I(0)
LnAJT	-3.43 (0.057)	-10.65 (0.00)	I(0)	LnYJT	-6.95 (0.00)	-14.84 (0.00)	I(0)
LnAPT	-1.87 (0.662)	-10.42 (0.00)	I(1)	LnYPT	-4.56 (0.0026)	-12.70 (0.0001)	I(0)
LnASG	0.25 (0.756)	-2.68 (0.0081)	I(1)	LnYSG	-2.43 (0.3610)	-9.90 (0.00)	I(1)
LnRAIN	-1.64 (0.766)	-8.02 (0.00)	I(1)	LnFER	-1.73 (0.7288)	-10.11 (0.00)	I(1)
LnIRRI	-1.89 (0.649)	-8.10 (0.00)	I(1)	LnCRI	-1.64 (0.7657)	-8.15 (0.00)	I(0)

Critical Value: 1% (-4.10), 5% (-3.48), 10% (-3.17)

Note: *AAP, AWP, ASP, ATP, AWT, ATR, ARM, AJT, APT, ASG indicate – area under autumn paddy, winter paddy, summer paddy, total paddy, wheat, tur, mustard, jute, potato and sugarcane respectively. Similarly, YAP, YWP, YSP, YTP, YWT, YTR, YRM, YJT, YPT, YSG represent yield of autumn paddy, winter paddy, summer paddy, total paddy, wheat, tur, mustard, jute, potato and sugarcane respectively. Also, RAIN, IRRI, FER, CRI represent rainfall, irrigation, fertiliser and cropping intensity.*

More or less a similar picture is observed in the growth of area, production and yield during various sub-periods from the result of linear spline regression model (*Table 2*). Only, there was very high growth of area and yield of summer paddy that resulted in significant production growth during Period I. However, during Period II, decline in yield was observed and it bounced back during Period III. In case of total paddy, annual exponential growth rate of area under cultivation and production decelerated, while yield growth recorded an accelerated trend from Period I to Period III. During Period I, there were marked growth in production of all the crops except jute and it was the result of both area and yield growth. But, during Period II, trends of production, area and yield of autumn and summer paddy, potato and sugarcane were negative. During Period III, improvement in yield was observed for wheat, potato and sugarcane as compared to the previous period. In general, there has been a decelerating trend in area of several crops over the periods except for a few crops. However, growth rate of yield improved for most of the crops due to better application of modern agricultural inputs and implements.

3.2 Unit Root Test Results

Bound testing approach is necessitated for all the variables to be integrated of I(0) or I(1) or of both nature but not integrated of I(2) for the computation of F-statistics. In order to find the order of integration, Augmented

Dickey Fuller test is employed. The results reveal that log of area under all the crops are I(1) except area under jute, which is stationary (*Table 3*). On the other hand, log of yield of winter and summer paddy, wheat, mustard, jute, potato and cropping intensity are stationary (i.e., I(0)) while, the other variables including log of yields of other crops, rainfall, irrigation, fertilizer are non-stationary (i.e. I(1)).

3.3 Lag Selection Criteria and ARDL Bound Test Cointegration

Before applying ARDL bound test to check for any cointegration among yield of a crop, area under crop, rainfall, use of fertilizer, irrigation and cropping intensity; it is necessary to select an appropriate lag order of the variable. The optimal ARDL model for the dependent variables has been chosen based on the Akaike Information Criterion, which is presented in Table 4. It is observed that lag 1 is the best fit for the chosen sample size. Also, the findings of cointegration test on the basis of ARDL bound testing approach are displayed in *Table 4*. The F-statistics are greater than upper bound values at 1% level of significance for the dependent variables LnYAP, LnYWP, LnYSP, LnYTR, LnYRM, LnYJT, LnYPT and LnYWT, which confirms the presence of long run relationship among the variables under consideration. In case of dependent variables LnYTP and LnYSG, the computed value of F-statistics falls below the lower bound values and thus the null hypothesis of no cointegration cannot be rejected. Even if there is no cointegration, one may estimate the short run relationship between the variables under consideration but not the long run one.

Table 4. ARDL Cointegration Bound Test Results

Dependent Variables	*Optimal Lag Structure*	*F-Statistics*
LnYAP	(1,0,0,1,1,0)	7.462054***
LnYWP	(1,0,0,0,0,1)	4.796705***
LnYSP	(1,3,2,1,0,1)	5.075069***
LnYTP	(1,1,1,0,1,0)	1.947115
LnYWT	(1,0,0,0,0,1)	4.683062**
LnYTR	(1,1,0,0,0,0)	6.397678***
LnYRM	(1,0,1,0,0,1)	5.984123***
LnYJT	(1,0,0,0,0,0)	9.024761***
LnYPT	(1,1,0,1,0,0)	5.813036***
LnYSG	(1,0,0,0,0,0)	2.213922

Critical Values (%):	1	5	10
Lower Bound *I(0)*:	3.41	2.62	2.26
Upper Bound *I(1)*:	4.68	3.79	3.35

***Note*:** *** and ** indicate significance at 1% and 5% level respectively.

3.4 Long Run and Short Run Analysis

Table 5 presents the short-run and long-run coefficients estimated by using ARDL Model (Eq. 11). For yield of autumn paddy, none of the short-run coefficients is found to be statistically significant. But the long run coefficients of lagged yield of autumn paddy and its area under cultivation is statistically significant. In the long run, negative coefficient of area under autumn paddy indicates inverse relationship between yield and area. For yield of winter paddy, both the short and long run coefficients of area under cultivation are positive, while rainfall has significant positive relation in the long run, but it adversely affects in the short run. Cropping intensity is found to have negative relationship with yield of winter paddy in the short run, though it is positively related in the long run. These results suggest the long run positive association for the growing application of fertilizer.

In case of yield of summer paddy, the area under cultivation and rainfall has significant positive association. In the short run, most of the variables have significant inverse association; while in the long run, area under cultivation, rainfall, fertilizer, irrigation and cropping intensity have significant positive relation. The coefficient of consumption of fertilizer and cropping intensity are positive in case of yield of summer paddy, indicating the intensive practice of it with the passage of time. The result further reveals that for 1% increase in consumption of fertilizer, yield of paddy overall is increased by 0.12%.

In case of wheat, cropping intensity has significant short-run negative association with yield. For each 1% increase in cropping intensity, overall yield of wheat is decreased by 0.06%. In case of yield of jute, irrigation has significant positive association in the long run. In this case, for 1% increase in irrigation facility caused increase in yield of jute by 0.0113%. As cultivation of jute is dependent on warm and wet climate, availability of irrigation facility helps to increase yield of jute. In case of yield of tur, in the short run rainfall and irrigation are found to have positive association while area has negative association. Area under cultivation cannot be increased as cultivation of tur coincides with the timing of winter paddy in Assam (June-July). Rainfall and irrigation facility boost tur production in the short run. Whereas in the long run, rainfall and irrigation have negative association with yield; but fertilizer and cropping intensity have significant positive association.

Table 5. Results of ARDL Models Exhibiting Short- and Long Run Coefficients

Variables	*Coefficient*	*t-Statistic*	*Variables*	*Coefficient*	*t-Statistic*
Dependent Variable: D(LnYAP)			*Dependent Variable: D(LnYWP)*		
C	8.4681***	3.7107 (0.0005)	C	0.9608	0.2774 (0.7826)
D(LnYAP(-1))	-0.1438	-0.9275 (0.3582)	D(LnYWP(-1))	-0.2375*	-1.7534 (0.0858)
D(LnAAP)	-0.1555	-0.3858 (0.7013)	D(LnAWP)	0.4848*	1.7130 (0.0930)
D(LnAAP(-1))	-0.0182	-0.0439 (0.9651)	D(LnAWP(-1))	0.5507*	1.9413 (0.0580)
D(LnRAIN)	0.0049	0.2487 (0.8046)	D(LnRAIN)	-0.0073	-0.7997 (0.4277)
D(LnRAIN(-1))	0.0681	0.3731 (0.7106)	D(LnRAIN(-1))	0.2149**	2.6110 (0.0119)
D(LnFER)	0.1689	1.2422 (0.2201)	D(LnFER)	0.0778	1.2444 (0.2193)
D(LnFER(-1)	-0.0604	-0.4210 (0.6756)	D(LnFER(-1)	-0.1048	-1.5044 (0.1389)
D(LnIRRI)	-0.0075	-0.5801 (0.5645)	D(LnIRRI)	-0.0004	-0.0754 (0.9402)
D(LnIRRI(-1))	0.0011	0.0930 (0.9263)	D(LnIRRI(-1))	0.0076	1.3704 (0.1768)
D(LnCRI)	0.1112	0.4192 (0.6768)	D(LnCRI)	0.0142	0.1166 (0.9076)
D(LnCRI(-1))	-0.0041	-0.1278 (0.8988)	D(LnCRI(-1))	-0.0293*	-1.9528 (0.0566)
LnYAP(-1)	-0.7187***	-3.6599 (0.0006)	LnYWP(-1)	-0.3798***	-2.8037 (0.0072)
LnAAP(-1)	-0.3000***	-3.0869 (0.0033)	LnAWP(-1)	0.0965	0.3628 (0.7182)
LnRAIN(-1)	-0.1262	-0.6512 (0.5179)	LnRAIN(-1)	-0.2154**	-2.4595 (0.0175)
LnFER(-1)	0.0167	0.5133 (0.6100)	LnLnFER(-1)	0.0399**	2.3460 (0.0231)
LnIRRI(-1)	0.0049	0.6653 (0.5090)	LnIRRI(-1)	-0.0026	-0.7500 (0.4568)
LnCRI(-1)	0.2182	0.6941 (0.4909)	LnCRI(-1)	0.3407**	2.3499 (0.0228)
Dependent Variable: D(LnYSP)			*Dependent Variable: D(LnYWT)*		
C	2.6708***	3.8898 (0.0003)	C	3.2792***	3.4182 (0.0013)
D(LnYSP(-1))	-0.1840	-1.2932 (0.2020)	D(LnYWT(-1))	-0.0102	-0.0757 (0.9399)
D(LnASP)	-0.0270	-0.2803 (0.7804)	D(LnAWT)	-0.0847	-0.8080 (0.4230)
DLn (ASP(-1))	0.2386**	2.6004 (0.0123)	D(LnAWT(-1))	0.0493	0.5198 (0.6055)
D(LnRAIN)	-0.0055	-0.2938 (0.7701)	D(LnRAIN)	-0.0064	-0.3255 (0.7462)
D(LnRAIN(-1))	0.2856*	1.7954 (0.0788)	D(LnRAIN(-1))	0.2189	1.2314 (0.2240)
D(LnFER)	0.1807	1.3192 (0.1932)	D(LnFER)	0.0908	0.6573 (0.5141)
D(LnFER(-1)	0.0437	0.3326 (0.7409)	D(LnFER(-1)	0.0949	0.6366 (0.5273)
D(LnIRRI)	-0.0070	-0.6059 (0.5474)	D(LnIRRI)	-0.0079	-0.6138 (0.5421)
D(LnIRRI(-1))	0.0063	0.5644 (0.5750)	D(LnIRRI(-1))	0.0069	0.5601 (0.5779)
D(LnCRI)	0.1790	0.7607 (0.4505)	D(LnCRI)	-0.1264	-0.4743 (0.6373)
D(LnCRI(-1))	-0.0155	-0.5377 (0.4505)	D(LnCRI(-1))	-0.0641*	-1.7074 (0.0941)
LnYSP(-1)	-0.3839***	-3.2991 (0.0018)	LnYWT(-1)	-0.5776***	-4.0631 (0.0002)
LnASP(-1)	-0.2017**	-2.0437 (0.0464)	LnAWT(-1)	0.0296	0.6629 (0.5105)
LnRAIN(-1)	-0.3913**	-2.4899 (0.0162)	LnRAIN(-1)	-0.1568	-0.9141 (0.3651)
LnFER(-1)	0.2325***	3.0067 (0.0042)	LnFER(-1)	0.0279	1.0221 (0.31180
LnIRRI(-1)	-0.0168**	-2.4926 (0.0161)	LnIRRI(-1)	-0.0106	-1.2688 (0.2105)
LnCRI(-1)	0.6539**	2.5502 (0.0139)	LnCRI(-1)	0.3003	1.0945 (0.2791)

Table 5. (continuance).

Dependent Variable: D(LnYJT)			Dependent Variable: D(LnYTR)		
C	5.4109**	2.0454 (0.0462)	C	5.4762***	5.8885 (0.0000)
D(LnYJT(-1))	-0.1052	-0.7283 (0.4698)	D(LnYTR(-1))	-0.0019	-0.0269 (0.9786)
D(LnAJT)	0.1727	0.8890 (0.3783)	D(LnATR)	-0.2331***	-3.2510 (0.0021)
D(LnAJT(-1))	0.0237	0.1305 (0.8976)	D(LnATR(-1))	-0.0849	-1.2263 (0.2259)
D(LnRAIN)	-0.0038	-0.2288 (0.8200)	D(LnRAI)	-0.0030	-0.3285 (0.7439)
D(LnRAIN(-1))	0.0708	0.4713 (0.6395)	D(LnRAIN(-1))	0.2572***	3.1354 (0.0029)
D(LnFER)	0.0179	0.1587 (0.8745)	D(LnFER)	-0.0708	-1.0833 (0.2840)
D(LnFER(-1)	-0.1258	-1.0903 (0.2809)	D(LnFER(-1)	-0.0666	-0.9693 (0.3371)
D(LnIRRI)	0.0155	1.4866 (0.1435)	D(LnIRRI)	0.0033	0.5471 (0.5868)
D(LnIRRI(-1))	-0.0045	-0.4396 (0.6621)	D(LnIRRI(-1))	0.0128**	2.1004 (0.0409)
D(LnCRI)	-0.2019	-0.8780 (0.3842)	D(LnCRI)	0.0525	0.4320 (0.6676)
D(LnCRI(-1))	0.0376	1.3418 (0.1858)	D(LnCRI(-1))	-0.0041	-0.2558 (0.7992)
LnYJT(-1)	-0.8124***	-4.2045 (0.0001)	LnYTR(-1)	-0.9109***	-12.234 (0.0000)
LnAJT(-1)	0.0001	0.0010 (0.9991)	LnATR(-1)	0.0218	0.2828 (0.7785)
LnRAIN(-1)	0.0604	0.4108 (0.6830)	LnRAIN(-1)	-0.2837***	-3.6058 (0.0007)
LnFER(-1)	0.0540	1.3323 (0.1889)	LnFER(-1)	0.0412***	2.8949 (0.0056)
LnIRRI(-1)	0.0113*	1.8584 (0.0691)	LnIRRI(-1)	-0.0144***	-2.8385 (0.0066)
LnCRI(-1)	-0.1108	-0.4597 (0.6477)	LnCRI(-1)	0.4493***	3.5421 (0.0009)
Dependent Variable: D(LnYRM)			**Dependent Variable: D(LnYPO)**		
C	1.3817	0.5084 (0.6134)	C	4.6118	1.5119 (0.1370)
D(LnYRM(-1))	-0.1971	-1.4302 (0.1590)	D(LnYPO(-1))	-0.2125	-1.4571 (0.1515)
D(LnARM)	0.2678	0.8009 (0.4270)	D(LnAPO)	0.8399*	2.0022 (0.0508)
D(LnARM(-1))	-0.0137	-0.0496 (0.9606)	D(LnAPO(-1))	-0.3767	-0.7765 (0.4411)
D(LnRAIN)	-0.0014	-0.0973 (0.9228)	D(LnRAI)	0.0336	1.1679 (0.2485)
D(LnRAIN(-1))	0.1537	1.0793 (0.2857)	D(LnRAIN(-1))	0.1903	0.7926 (0.4318)
D(LnFER)	0.1028	0.9302 (0.3568)	D(LnFER)	0.2187	1.2009 (0.2355)
D(LnFER(-1)	0.0498	0.3988 (0.6917)	D(LnFER(-1)	0.1421	0.7817 (0.4381)
D(LnIRRI)	-0.0100	-0.8490 (0.4000)	D(LnIRRI)	0.0160	0.9467 (0.3484)
D(LnIRRI(-1))	0.0070	0.5618 (0.5768)	D(LnIRRI(-1))	-0.0069	-0.4290 (0.6698)
D(LnCRI)	0.1447	0.6736 (0.5037)	D(LnCRI)	0.1565	0.4308 (0.6684)
D(LnCRI(-1))	-0.0243	-0.8531 (0.3977)	D(LnCRI(-1))	-0.0705*	-1.6977 (0.0959)
LnYRM(-1)	-0.5169***	-3.1367 (0.0029)	LnYPO(-1)	-0.5214***	-3.3199 (0.0017)
LnARM(-1)	0.1220	0.5376 (0.5933)	LnAPO(-1)	-0.0255	-0.0795 (0.9369)
LnRAIN(-1)	-0.2881**	-2.0239 (0.0484)	LnRAIN(-1)	-0.2677	-1.0893 (0.2813)
LnFER(-1)	0.0391	1.6363 (0.1082)	LnFER(-1)	0.0052	0.0725 (0.9425)
LnIRRI(-1)	-0.0134	-1.0076 (0.3186)	LnIRRI(-1)	0.0096	0.7100 (0.4810)
LnCRI(-1)	0.4560*	1.9276 (0.0597)	LnCRI(-1)	0.4635	1.1528 (0.2546)
Dependent Variable: D(LnYTP)			**Dependent Variable: D(LnYSG)**		
C	0.0081	0.7707 (0.4441)	C	0.0676	1.0211 (0.3117)
D(LnYTP(-1))	-0.4305***	-3.3675 (0.0014)	D(LnYSG(-1))	-0.2432*	-1.8680 (0.0671)
D(LnATP)	0.4936*	1.7520 (0.0853)	D(LnASG)	-1.0649	-1.1841 (0.2415)
D(LnATP(-1))	0.3612	1.2608 (0.2127)	D(LnASG(-1))	-1.7276*	-1.9538 (0.0558)
D(LnRAIN)	-0.0020	-0.2377 (0.8129)	D(LnRAI)	0.0199	0.4213 (0.6751)
D(LnRAIN(-1))	0.0311	0.4786 (0.6341)	D(LnRAIN(-1))	0.0009	0.0025 (0.9980)
D(LnFER)	0.1180**	2.0270 (0.0475)	D(LnFER)	-0.2333	-0.6233 (0.5357)
D(LnFER(-1)	-0.0605	-0.9652 (0.3386)	D(LnFER(-1)	-0.0342	-0.0879 (0.9303)
D(LnIRRI)	-0.0015	-0.2674 (0.7901)	D(LnIRRI)	0.0152	0.5012 (0.6182)
D(LnIRRI(-1))	0.0046	0.8610 (0.3930)	D(LnIRRI(-1))	0.0087	0.2971 (0.7675)
D(LnCRI)	-0.0356	-0.3425 (0.7332)	D(LnCRI)	0.0012	0.0020 (0.9984)
D(LnCRI(-1))	-0.0213	-1.5729 (0.1215)	D(LnCRI(-1))	0.0596	0.7715 (0.4437)

Notes: (1) ***, ** and * indicates significant levels at 1%, 5% and 10% respectively.
(2) Figures in parentheses indicate probability value.

In case of yield of mustard, none of the short run coefficients, is statistically significant. The cointegrating coefficient of rainfall is significantly negative, while that of cropping intensity is positive. Further, in the short run area under cultivation has significant positive association with the yield of potato and cropping intensity has significant negative association with it. In the long run, lagged value of yield itself has significant negative association and none of the other variables are found to be statistically significant. For yield of sugarcane, only area has been found to have negative association in the short run.

3.5 ARDL-Error Correction Model

The results of the error correction model reveal that for yield of all the crops, coefficients of ECM terms are negative and significant (*Table 6*). The error correction term is less than 1 and significant, indicating the short run adjustment for any shock towards long run equilibium. The higher values of ECM show relatively faster adjustment process for any short-run deviation from long run equilibrium, which is found in case of tur, jute, autumn paddy (the so-called inferior crops (De & Bodosa, 2015)) as compared to that of summer paddy, potato, mustard. Whereas, the oefficients of other variables have expected sign but not significant in most of the cases due to their poor growth like irrigation, chemical fertiliser etc as observed before.

Table 6. Results of Estimated Error Correction Model

Variables	*Coefficient*	*t-Statistic*	*Variables*	*Coefficient*	*t-Statistic*
Dependent Variables: D(LnYAP)			***Dependent Variables: D(LnYWP)***		
C	0.0023	0.1019 (0.9191)	C	0.0048	0.4383 (0.6629)
D(LnYAP(-1))	-0.1586	-1.1148 (0.2698)	D(LnYWP(-1))	-0.2486*	-1.8487 (0.0700)
D(LnAAP)	-0.2428	-0.8964 (0.3740)	D(LnAWP)	0.6493**	2.4890 (0.0159)
D(LnAAP(-1))	-0.1334	-0.4888 (0.6269)	D(LnAWP(-1))	0.5532**	2.0440 (0.0458)
D(LnRAIN)	0.0042	0.2295 (0.8193)	D(LnRAIN)	-0.0097	-1.1019 (0.2754)
D(LnRAIN(-1))	0.0114	0.0826 (0.9344)	D(LnRAIN(-1))	0.1006	1.4894 (0.1422)
D(LnFER)	0.1691	1.4373 (0.1564)	D(LnFER)	0.0815	1.3685 (0.1768)
D(LnFER(-1)	-0.0748	-0.6015 (0.5500)	D(LnFER(-1)	-0.0833	-1.2619 (0.2124)
D(LnIRRI)	-0.0068	-0.5910 (0.5570)	D(LnIRRI)	-0.0012	-0.2286 (0.8200)
D(LnIRRI(-1))	0.0036	0.3229 (0.7480)	D(LnIRRI(-1))	0.0072	1.3525 (0.1818)
D(LnCRI)	-0.0050	-0.0229 (0.9818)	D(LnCRI)	-0.1386	-1.2844 (0.2045)
D(LnCRI(-1))	0.0011	0.0386 (0.9693)	D(LnCRI(-1))	-0.0225	-1.6166 (0.1118)
ECM (-1)	-0.6665***	0.0003 (0.0003)	ECM(-1)	-0.3385**	-2.5524 (0.0136)
Dependent Variables: D(LnYSP)			***Dependent Variables: D(LnYWT)***		
C	-0.0005	-0.2541 (0.8003)	C	0.0021	0.0922 (0.9268)
D(LnYSP(-1))	-0.0882	-0.6299 (0.5314)	D(LnYWT(-1))	-0.0098	-0.0751 (0.9404)
D(LnASP)	0.0435	0.5169 (0.6073)	D(LnAWT)	-0.0093	-0.1148 (0.9090)
D(LnASP(-1))	0.1385	1.6063 (0.1140)	D(LnAAP(-1))	0.0936	1.1601 (0.2511)
D(LnRAIN)	-0.0144	-0.7827 (0.4372)	D(LnRAIN)	-0.0121	-0.6520 (0.5171)
D(LnRAIN(-1))	0.0805	0.5863 (0.5601)	D(LnRAIN(-1))	0.1368	0.9323 (0.3553)
D(LnFER)	0.0671	0.5331 (0.5961)	D(LnFER)	0.0255	0.2010 (0.8415)
D(LnFER(-1)	0.0490	0.3710 (0.7120)	D(LnFER(-1)	-0.0025	-0.0189 (0.9849)
D(LnIRRI)	-0.0002	-0.0192 (0.9847)	D(LnIRRI)	-0.0010	-0.0867 (0.9312)
D(LnIRRI(-1))	0.0047	0.4274 (0.6707)	D(LnIRRI(-1))	0.0034	0.2974 (0.7673)
D(LnCRI)	-0.1211	-0.5550 (0.5812)	D(LnCRI)	-0.2287	-0.9788 (0.3320)
D(LnCRI(-1))	0.0022	0.0782 (0.9379)	D(LnCRI(-1))	-0.0326	-1.0568 (0.2953)
ECM (-1)	-0.3453***	-2.9838 (0.0043)	ECM(-1)	-0.5452***	-4.0474 (0.0002)
Dependent Variables: D(LnYJT)			***Dependent Variables: D(LnYTR)***		
C	0.0101	0.5573 (0.5796)	C	0.0266*	1.8914 (0.0639)
D(LnYJT(-1))	-0.1113	-0.8071 (0.4231)	D(LnYTR(-1))	0.0968	1.0554 (0.2959)
D(LnAJT)	0.1756	1.0207 (0.3319)	D(LnATR)	-0.3302***	-4.1176 (0.0001)
D(LnAJT(-1))	-0.0216	-0.1392 (0.8898)	D(LnATR(-1))	0.0299	0.3809 (0.7047)
D(LnRAIN)	-0.0053	-0.3601 (0.7202)	D(LnRAIN)	0.0106	0.9338 (0.3546)
D(LnRAIN(-1))	0.1024	0.8411 (0.4039)	D(LnRAIN(-1))	0.0903	1.0156 (0.3143)
D(LnFER)	0.0473	0.4774 (0.6350)	D(LnFER)	-0.0666	-0.8599 (0.3936)
D(LnFER(-1)	-0.1005	-0.9634 (0.3396)	D(LnFER(-1)	-0.0265	-0.3261 (0.7456)
D(LnIRRI)	0.0126	1.3450 (0.1842)	D(LnIRRI)	0.0089	1.2343 (0.2224)
D(LnIRRI(-1))	-0.0024	-0.2686 (0.7892)	D(LnIRRI(-1))	0.0058	0.8098 (0.4216)
D(LnCRI)	-0.1501	-0.7863 (0.4351)	D(LnCRI)	-0.1214	-0.8590 (0.3941)
D(LnCRI(-1))	0.0291	1.1576 (0.2521)	D(LnCRI(-1))	-0.2221	-1.2099 (0.2316)
ECM (-1)	-0.7958***	-4.3302 (0.0001)	ECM(-1)	-0.8714***	-9.0149 (0.0000)

Table 6. (continuance).

Dependent Variables: D(LnYRM)			***Dependent Variables: D(LnYPO)***		
C	0.0011	0.0653 (0.9482)	C	-0.0299	-0.9080 (0.3679)
D(LnYRM(-1))	-0.1681	-1.2362 (0.2217)	D(LnYPO(-1))	-0.2151	-1.5377 (0.1299)
D(LnARM)	0.4692	1.6052 (0.1143)	D(LnAPO)	0.9481**	2.4110 (0.0193)
D(LnARM(-1))	0.1041	0.4206 (0.6757)	D(LnAPO(-1))	-0.3990	-0.9619 (0.3404)
D(LnRAIN)	-0.0010	-0.0750 (0.9404)	D(LnRAIN)	0.0309	1.1577 (0.2521)
D(LnRAIN(-1))	0.0048	0.0412 (0.9672)	D(LnRAIN(-1))	0.0205	0.1078 (0.9145)
D(LnFER)	0.0741	0.7215 (0.4737)	D(LnFER)	0.1389	0.8906 (0.3771)
D(LnFER(-1)	-0.0065	-0.0581 (0.9538)	D(LnFER(-1)	0.0869	0.5215 (0.6041)
D(LnIRRI)	-0.0081	-0.8115 (0.4206)	D(LnIRRI)	0.0178	1.2007 (0.2351)
D(LnIRRI(-1))	-0.0003	-0.0322 (0.9744)	D(LnIRRI(-1))	-0.0069	-0.4685 (0.6413)
D(LnCRI)	-0.7216	-0.3858 (0.7011)	D(LnCRI)	-0.0072	-0.0239 (0.9810)
D(LnCRI(-1))	-0.0050	-0.2028 (0.8400)	D(LnCRI(-1))	-0.0487	-1.3032 (0.1980)
ECM (-1)	-0.5139***	-3.2134 (0.0022)	ECM(-1)	-0.5030***	-3.3511 (0.0015)

Note: *, ** and **** indicates significant levels at 10%, 5% and 1% respectively
Figures in parentheses indicate probability value

3.6 Diagnostics Checking for Stability of the Model

The goodness of fit of the ARDL and error correction model, is tested by using the CUSUM and CUSUMQ tests after confirming the cointegration relationship among variables in order to examine stability of the model both in the short and long run. CUSUM and CUSUMQ tests are conducted based on the recursive regression residuals for both ARDL and ECM (Brown et al, 1975). If the plots of the statistics lie within the critical bounds at 5% level of significance, it can be concluded that calculated results of the coefficients of both ARDL model and ECM are stable. The stability of the model is shown in *Figure 1* and *2*, and goodness of fit of most of the model.

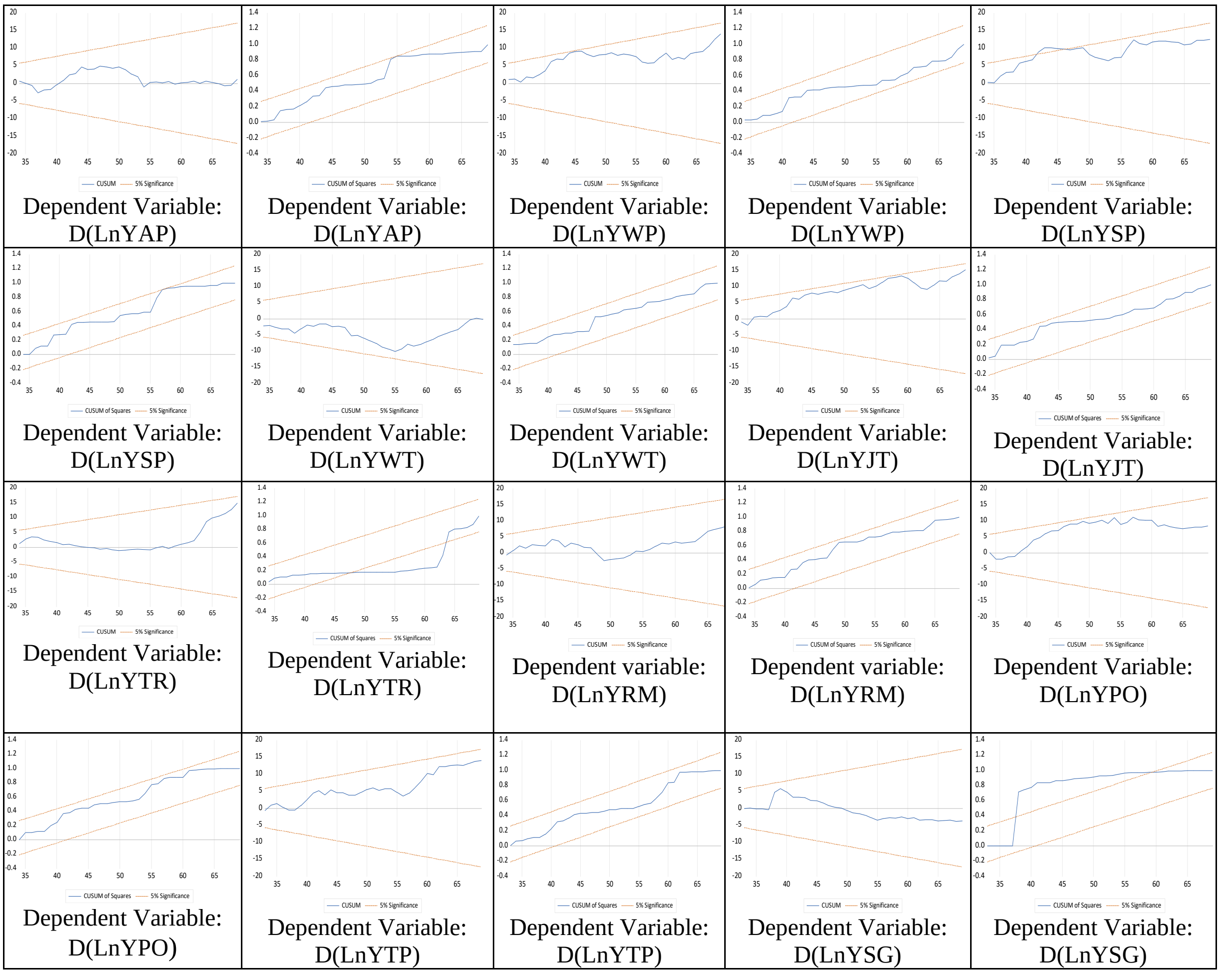

Figure 1. Plot of CUSUM (1st) and CUSUMQ (2nd) for Each Variable for Coefficient Stability of ARDL Model

is found to be significant, implying the model to be stable excepting for summer paddy for CUSUM (ARDL); and tur and sugarcane for CUSUMQ (ARDL) and tur CUSUM (ECM).

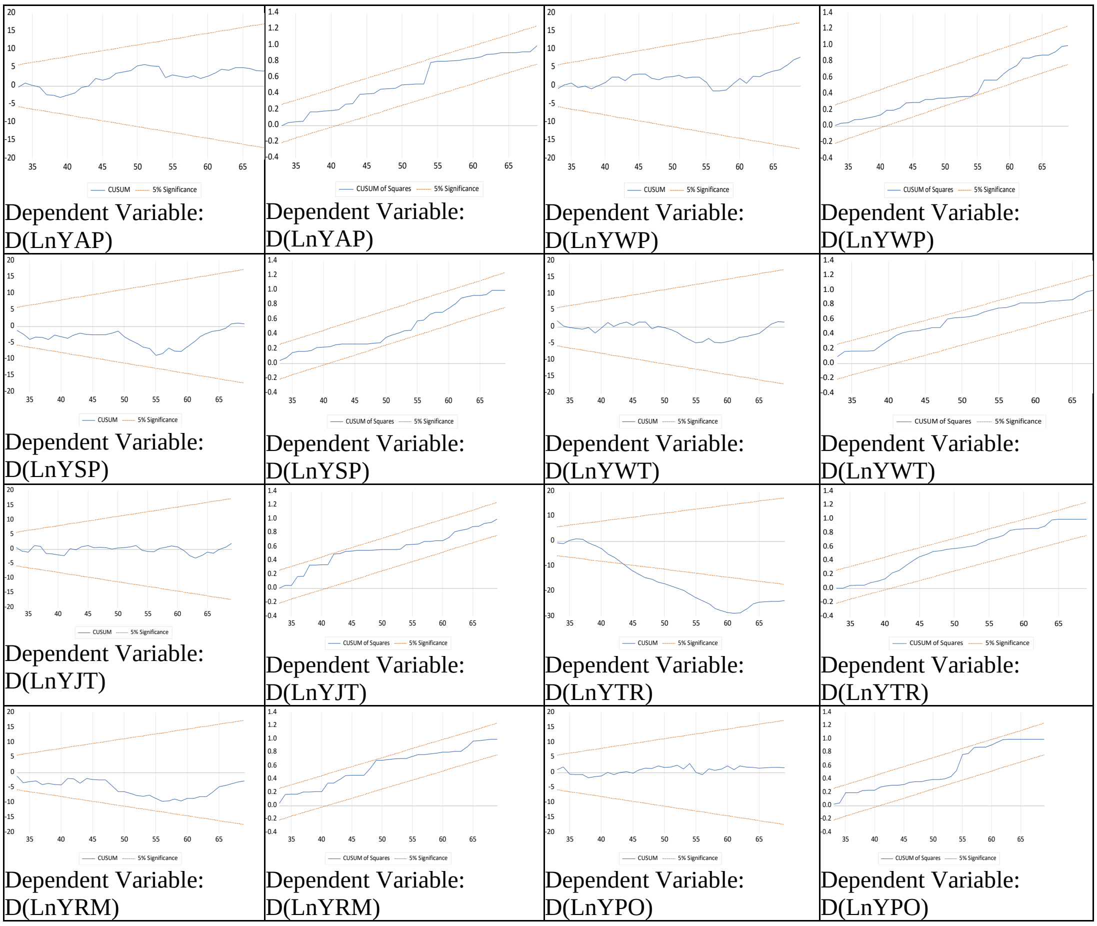

Figure 2. Plots of CUSUM (1st) and CUSUMQ (2nd) for Each Variable for Coefficient Stability for Error Correction Model

3.7 Changes in Cropping Pattern Examined through Diversification Index and Proportion of GCA under Various Crops

Values of Herfindahl and Simpson Indices reveal gradual diversification of crops in Assam over the years but with a slower pace (*Table 7*). Cropping pattern in any region ultimately depends upon food habit, prices, agro-climatic conditions, market avenues, government policies and infrastructure. Cropping pattern in Assam is still dominated by paddy (rice) with a total 60.43 per cent of GCA under cultivation during 2017-20 (*Table 8*). Area under autumn paddy increased marginally in 1950s and after 1970 it started declining till 2017-20. Development of minor irrigation (shallow tube-well) has given some momentum to cultivators of summer paddy. The harvest time for summer paddy is March to May. So, the farmers find it convenient to cultivate this in order to avoid the risk of flood that affects more frequently in case of autumn paddy.

The autumn and winter paddy are found to lose area to some relatively more remunerative crops in the earlier years. But the process has lost momentum in past two decades. Cultivation of wheat increased during early 1980s but declined afterwards till 2017-20. It is now more concentrated in summer paddy, potato, and mustard. In some region however, the cultivation of inferior crops has increased due to poor irrigation facility, agro-infrastructure and technological support as well as risk averse behavior of cultivators (De and Bodosa, 2015).

Table 7. Herfindahl and Simpson Indices of Selected Crops in Assam

Year	*Herfindahl Index*	*Simpson Index*
1951-54	0.93	0.07
1961-64	0.90	0.09
1971-74	0.85	0.15
1981-84	0.74	0.26
1991-94	0.74	0.26
2001-04	0.73	0.27
2011-14	0.60	0.40
2017-20	0.60	0.40

Source: Computed from data published by the Directorate of Economics and Statistics, Government of Assam, Statistical Handbook of Assam (Various Issues).

Table 8. Changes in Share of Area under Crops to GCA (Per cent)

Crops	*1951-54*	*1961-64*	*1971-74*	*1981-84*	*1991-94*	*2001-04*	*2011-14*	*2017-20*
Autumn Paddy	16.07	18.67	19.53	18.09	17.33	12.68	5.98	3.55
Winter Paddy	58.32	55.32	52.19	48.60	47.88	47.31	45.45	46.92
Summer Paddy	0.29	0.45	1.31	1.11	3.67	8.80	9.60	9.96
Total Paddy	74.69	74.44	73.03	67.80	68.89	68.79	61.03	60.43
Wheat	0.11	0.13	1.74	3.00	2.08	1.91	0.85	0.38
Tur	0.18	0.12	0.22	0.25	0.17	0.19	0.14	0.14
Rape & Mustard	5.38	5.16	5.28	7.62	7.92	7.21	6.53	7.12
Jute	5.52	5.52	4.89	3.29	2.45	1.81	1.62	1.66
Potato	0.89	0.99	0.96	1.25	1.72	2.11	2.36	2.59
Sugarcane	1.19	1.17	1.27	1.46	1.03	0.70	0.70	0.76

Source: Computed from data published by the Directorate of Economics and Statistics, Government of Assam, Statistical Handbook of Assam (Various Issues).

3.8 Decomposition Analysis

Growth in agricultural production is the result of growth in area, yield, cropping pattern and interactions among themselves. Thus, decomposition analysis is carried out to compute the effect of area, yield, cropping pattern and their interactions to the changes in output. During the period prior to Green Revolution, 28.08 per cent of the growth in agricultural output was contributed by area growth, 18.72 per cent by yield growth and 36.40 per cent due to cropping pattern effect (*Table 9*). The combined interaction effects resulted in 16.8 per cent of change in total agricultural output of which, interaction of area and cropping pattern was the highest. Thus, during the first phase after Independence, cropping pattern change was the largest contributor, followed by area and then yield to the growth of agricultural output. During Period II (Green Revolution) yield effect was the highest (43.95 per cent) for the application of seed-fertilizer-irrigation technology, while the area effect was reduced to 15.67 per cent, and area-yield interaction effect was 18.19 per cent and cropping pattern effect also declined to 11.97 per cent. The other interaction effects were negligible.

During period III, yield effect continued to increase and remains the highest contributor to the growing agricultural output (80.21 per cent); followed by area effect (28.75 per cent) and the interaction of area & yield (13.36 per cent). The other factors such as cropping pattern and the interaction of area & cropping pattern, cropping pattern & yield, and area, yield and cropping pattern have negative contribution to the agricultural output growth. The results suggest that the source of growth have changed dramatically over different periods. Since the scope of area expansion became insignificant, its contribution to the increased output has been diminishing gradually. The yield effect increased significantly over the periods due to growing use of modern agricultural inputs and implements through government support and the efforts of stakeholders. However, Assam still lags behind the agriculturally developed states of the country in terms of yield in crops as well as use of modern inputs. Thus, there are significant scopes in these fronts and efforts need to be directed to improve yield and diversify cultivation practices towards higher-value crops to further raise agricultural earning.

Table 9: Relative Contribution of Various Components to the Growth of Selected Crops Total Output in Assam during 1951-52 to 2019-20 (per cent)

Components	*Period I*	*Period II*	*Period III*
Area Effect	28.08	15.67	28.75
Yield Effect	18.72	43.95	80.21
Cropping Pattern Effect	36.40	11.97	-11.40
Area & Cropping Pattern Effect	7.31	4.95	-1.90
Area & Yield Effect	3.76	18.19	13.36
Cropping Pattern & Yield Effect	4.77	3.73	-7.73
Area, Yield & Cropping Pattern Effect	0.96	1.54	-1.29

Source: Computed from data published by the Directorate of Economics and Statistics, Government of Assam, Statistical Handbook of Assam (Various Issues).

4. Conclusions

This paper analyzes the pattern of agricultural growth in Assam, India since independence. Though winter paddy, is the principal crop for being the staple food item, its share in gross cultivated area declined over time. Mustard, potato and summer paddy however recorded continuous growth, which got accelerated and occupied central position in crop diversity during economic reform period along with commercialization of agriculture, and supported by much needed modern technological inputs and implements. Notwithstanding the slow pace, the diversity and adaptability followed a similar pattern like that of the major eastern states of India (De, 2003) along with the progress of garden crops especially tea (De and Bodosa, 2015; De and Pal, 2019).

The growth of production of paddy, wheat, tur and sugarcane during Period I was mainly due to area expansion and in Period II due to both yield and area growth. However, this increase in production and area was short-lived for autumn paddy, wheat and sugarcane, but for others it has been significantly positive. Yield growth rate has been on continuous rise for all the crops except potato and sugarcane. Deceleration in area and production continued for jute, autumn paddy, tur, wheat during Period III but rate of decline in production was slower than that of area growth with accelerated growth in yield. Autumn and winter paddy, jute and sugarcane have been losing area to summer paddy, mustard and potato that recorded steady growths in area and yield (De and Bodosa, 2015). HYV paddy cultivation accounts to 78 per cent of total paddy during 2017-20, which was 40 per cent during 1981-84. Also, diversification towards some low value crops has been observed in the previous decades due to uncertain weather conditions and unmatched progress of irrigation. It may be highlighted that area under jute has been reduced in Assam along with its production. As jute requires hot and humid conditions to grow, it depends on wellmaintained irrigation for the erratic behaviour of rainfall. But the irrigation facility is not well developed in Assam. This possibly explains the reduction in area under cultivation of jute in Assam.

The decomposition analysis showed that area, yield and the area-yield interaction effects have positive effects on agricultural output. Initially, effect of cropping pattern and area assumed greater role in the growth of agricultural output, but their effects declined and yield effect became the strongest during period II and III, with the gradual expansion of modern technology. In Assam use of modern technology got slow progress and lagged behind other parts of Indiaby around two decades. There is a visible gap in utilization of irrigation potential. Out of 1002 thousand hectares irrigation potential created in 2017-20, net area irrigated was only 209 thousand hectares (about 21 per cent) with low coverage of canal irrigation.

The ARDL bounds testing approach confirmed the long-term relationship of yield of all varieties of paddy, wheat, tur, mustard, potato and jute with the so-called advanced technology. Area and consumption of fertilizer are positively associated with the yield of winter and summer paddy, but rainfall and cropping intensity are inversely related to the yield of winter paddy. For wheat, cropping intensity is inversely related to the yield, while irrigation caused improved yield of jute though ultimately it saw a negative trend in area allocation over the years for the limited irrigation capacity utilisation. For rape & mustard it was mostly cropping intensity that has positively affected yield in the long run.

The long run cointegrating relation and ECM reveals self-adjustment process of any disequilibrium occurring in all the equations. The CUSUM and CUSUMQ tests confirm the goodness of fit of the models. Estimates of ARDL, ECM and graphs of CUSUM and CUSUMQ shows the long-run and short-run impact of elasticities of area under cultivation, rainfall, fertilizer, cropping intensity and irrigation on yield of crops grown in Assam. This results is validated with the help of CUSUM and CUSUMQ graphs, which confirms the stability of ARDL and ECM model for majority of the crops taken under consideration.

Use of agricultural implements has been rising but not at a slower pace to enhance agricultural productivity and efficiency of farmers remarkably. Such slow progress of modern farming technique hinders adoption of desired crop diversity and contribution of cropping pattern change has not been rising in desired direction. Adoption of seed-fertilizer-irrigation technology in Assam is still at the midway as compared to the developed agricultural zones of India. Thus, there is still enough space to improve the productivity of crops further and judicious use of resources to raise profitability of the farmers through crop diversity. The recommendations to improve yield on crops can be designed according to crop specific characteristics. As each crop requires different environment and inputs for its growth, the focus should be placed specifically on physical and technological inputs, especially in extreme climatic conditions. Technological innovation in any agro-climatic zone may help in moderating adverse impacts of extreme climatic events and choose the desired cropping pattern.

Although the study is conducted in Assam, the largest North-Eastern state of India, under the similar agro-climatic conditions of sub-Himalayan India, the same result can be replicated for other areas too. Technological breakthrough is very important to benefit the farmers in the long run. Irrigation facility should be created to respond to erratic rainfall. Use of chemical fertilizer has been significant in improving yield of crops. However, considering sustainability approach as observed in other regions, overdose of chemical fertilizer (wherever observed) needs to be sensitized (Khajuria, 2016; Bora, 2022). The farmers should be given proper training on soil testing and appropriate recommendation of fertilizer dosage. Infrastructural facility such as cold storage needs to be developed for the preservation of perishable crops. Thus, the outcome of this study is relevant and has significant policy implications for any region with varied agroclimatic condition and depending on the local topographic and climatic conditions; suitable cropping pattern with technology needs to be applied.

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