Spatial and Temporal Dynamics of Cultivated Area, Production and Productivity of Millets in North East Indiaand future projection using ARIMA approach

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ABSTRACT

Millets are an important but often overlooked group of cereal grains in global agriculture, with significant nutritional and agronomic value. India stands out as a millet cultivation leader, contributing significantly to global production and boasting a robust market poised for expansion. Millets are increasingly being recognized for their climate resilience and sustainable farming characteristics, in contrast to the productivity challenges that major staples such as wheat and rice face under changing climatic conditions. This study focuses on North East India (NEI), where millet cultivation is important for agricultural diversification and sustainability. Employing Man-Kendall test, the study examines historical trends in millet cultivated area, production, and productivity from 2000-2001 to 2022-2023, and then forecasting millet cultivated area and production using ARIMA models. The best fitted ARIMA model was found to be ARIMA (0, 0, 1) for millet cultivated area and ARIMA (2, 0, 1) (2, 0, 2) (2) for millet production. The models highlighted anticipated growth in millet cultivation and production by the year 2025-26, underscoring the potential for strategic agricultural planning and policy interventions. The study emphasizes the need for enhanced crop diversification, particularly in regions like Sikkim and Tripura which showed stagnant growth during the past decades, require enhanced crop diversification to optimize land use and enhance farming resilience against economic and environmental uncertainties. Moreover, this research aims to inform policymakers, agricultural stakeholders, and researchers about the spatial and temporal dynamics of millet cultivation in NEI, promoting sustainable agricultural practices and nutritional security in the face of global food security challenges.

Keywords: North East India, Millet, ARIMA, Man-Kendall, Forecast

1. INTRODUCTION

Today, global food security hinges largely on the performance of fewer than 10 key crops. Scientific advancements have predominantly focused on boosting the productivity of staples like rice, wheat, and maize, leading to the decline of numerous other traditional crops such as millets and pseudo cereals. Millets, a diverse group of small-seeded cereal grains, are well-suited to various tropical and subtropical climates and require minimal inputs for cultivation. They were among the first crops domesticated by ancient civilizations in Asia and Africa, later becoming crucial food sources worldwide. Major types of millets include sorghum (jowar), pearl millet (bajra), and smaller varieties such as finger millet (ragi), foxtail millet (*kangni*), kodo millet, little millet (*kutki*), proso millet (*cheena*), barnyard millet

(*jhangora*), and brown top millet (*korale*). They are highly nutritious in nature. For Example: Finger millet (*Elusinecoracana*), also known as *ragi* in India is gluten-free, rich in iron, calcium, tryptophan, methionine and other essential amino acids. Moreover, it offers a lower glycemic index, making it a favorable choice for dietary balance [1].With a shorter growth cycle, minimal need for irrigation, resilience to high salinity, and low input requirements during cultivation, this crop emerges as crucial for future human sustenance amid global population growth and increasing water scarcity [2]. Crops such as rice and wheat provide food security, but finger millet provides nutritional security to the world [3-4]
Millets are cultivated across approximately 12.45 million hectares worldwide, yielding about 15.53 million tonnes annually and contributing significantly, about 10%, to the country's total food grain production. Known as Nutri-cereals, millets are valued for their nutritional richness, resilience to climate variations, and ability to thrive in dryland conditions. They have garnered increasing attention due to their gluten-free nature and are recognized for their high content of polyphenols, antioxidants, and dietary fibres, essential for maintaining good health.

In hot and arid regions of developing nations, particularly in Africa and Asia, millets serve as a vital food source for impoverished farmers. These regions account for 97% of global millet production and consumption. India leads as the world's largest millet producer, with 26.6% of the global millet cultivation area and 83% of Asia's total millet cropping area [5]. Finger millet stands out as the most extensively cultivated minor millet in India, yielding 1.79 million tonnes from a total cropped area of 1.17 million hectares. Over 90% of India's finger millet production comes from key producing states such as Karnataka (58%), Uttarakhand, Maharashtra, Tamil Nadu, Odisha, and Andhra Pradesh [6]. Following wheat, rice, maize, sorghum, and pearl millet, finger millet ranks as the sixth most important crop in India.In 2022, India consumed about 4.45 million metric tons of sorghum, while the consumption of other types of millets surpassed 13 million metric tons [7].India stands as the global leader in millet production, accounting for approximately 40% of the world's total output, with an annual production of around 16 million metric tonnes. Moreover, India ranks as the second-largest exporter of millets, with exports growing steadily at a compound annual growth rate (CAGR) of 12% over the past three years. The millets market is poised for further expansion, projected to increase from its current value exceeding $9 billion to over $12 billion by 2025 [8].
According to the Consultative Group on International Agriculture Research (CGIAR), climate change may reduce global production of wheat, rice, and maize by 13–20% in the coming years. To meet the food requirements of an estimated 9 billion people by 2050 and counter this decline, global agricultural output must increase by approximately 70%. Millets have consistently shown strong productivity growth over the past five decades, in contrast to the variable productivity observed in major food crops [9]. Therefore, there is an urgent need to prioritize and expand global efforts in millet cultivation. Assam, a significant rice-producing region in India, exhibits a cropping intensity of 149%, indicating a lack of crop diversity and inefficient utilization of abundant resources. There is substantial potential for enhancing agricultural productivity and diversification, which could optimize land use. Diversifying crops in agriculture enhances resilience against crop failures and can substantially address issues of self-sufficiency and poverty. Repurposing fallow rice lands is crucial for ensuring livelihood security in Assam. Beyond providing additional income, this approach offers farmers opportunities for diversified farming activities year-round.
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income, this approach offers farmers opportunities for diversified farming activities year-round. Millets thrive particularly well in mixed and intercropping systems, making them a viable option for thousands of families in Assam, especially small-scale farmers and tribal communities. They thrive particularly well in mixed and intercropping systems, making them a viable option for thousands of families in Assam, especially small-scale farmers and tribal communities. This shift to millet cultivation has the potential to enhance farming efficiency. Currently, in Assam, small millets and other cereals cover a total area of 4,973 hectares, producing 3,268 tonnes annually with an average yield of 656 kg per hectare [10]. This shift to millet cultivation has the potential to enhance farming efficiency. Currently, in Assam, small millets and other cereals cover a total area of 4,973 hectares, producing 3,268 tonnes annually with an average yield of 656 kg per hectare [10].
The objective of the study was to investigate the spatial and temporal dynamics of millet cultivated area, production, and productivity in North East India using the ARIMA technique. Additionally, the study aimed to forecast future trends of millet farming based on the gathered data.

2. MATERIALS AND METHODS

2.1 Data used

Cultivated area, production and productivity data of small milletswhich was used for analysing the trend and for forecasting using ARIMA approach were obtained from Directorate of Economics & Statistics (DE&S), Ministry of Agriculture & Farmers' Welfare (MoA&FW), Government of India.The secondary data of annualarea, production and productivity for a period of 23 years (2000-2022) were collected for the present investigation and subsequently the data underwent thorough analysis to identify existing trends, whether upward or downward. Furthermore, the ARIMA model was utilized to generate forecasts of future trends for providing a critical insight that can become beneficial for strategic planning and informed decision-making within the agricultural sector.
The studywas carried out in North East India (NEI) which is situated in Eastern Himalayan region and bounded within $87^0$50' to $96^0$30' E Longitude and 21^0 08' to 30^0 12' N Latitude. The climate of NEI differs from that of the rest of India due to unique features such as orography, alternating pressure cells over NEI and the Bay of Bengal, and local mountain and valley winds. The abundance of water bodies and forest areas contribute to its unique climate.NEI is bifurcated into fourmeteorological subdivisionsand is designated by no. 2 (Arunachal Pradesh), 3(Assam and Meghalaya), 4 (Nagaland, Manipur, Mizoram and Tripura) and 5 (sub-Himalayan West Bengal and Sikkim) which was defined by India Meteorological Department (IMD, Pune) (Figure 1).However, in the present study, data from the states of Manipur and Mizoram were not included, as the cultivated area and production of millets in these two states are comparatively less than other seven Northeastern states. Therefore, their exclusion may unlikely impact the overall analysis and conclusions of the study.

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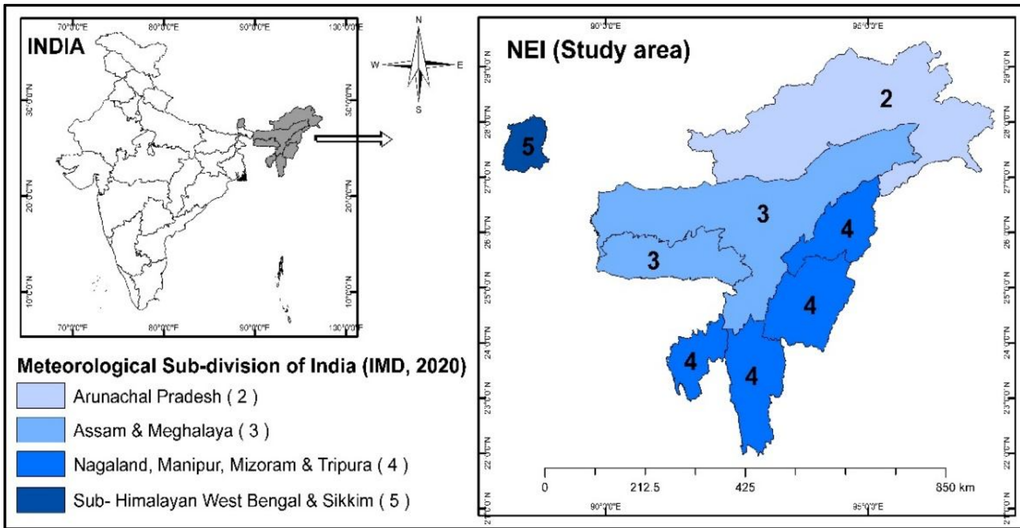

Figure 1. Location of the study area (North east India)

2.2Man-Kendall (MK) trend assessment

The trend of cultivated area, production and productivity of small millets were computed employing Mann- Kendall (MK) test [11] and the magnitude of the trend was estimated by Sen's slope estimator test [12]. The MK's test is a non-parametric test which is suitable for those types of datasets where the trend may assume to be monotonic and depending upon the number of values, two different types of statistics were performed i.e., if the values in the datasets are less than 10 in numbers then S-statistics is used and if more than 10, Z-statistics is used [13]. The S-statistics is computed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (x_j - x_i)$$

Where, Where, x_j and $x_i$are the annual values in years j and i, j $>i$ respectively, n is the number of data points and sign (x_j- x_i) is computed as:

$$\text{sign } (x_j\text{- } x_i) = \begin{cases} 1\ if\ xj - xi\ >\ 0 \\ 0\ if\ xj - xi\ =\ 0 \\ -1\ if\ xj - xi\ <\ 0 \end{cases}$$

The Z-statistics is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{var\ (S)}}\ if\ S\ >\ 0 \\ 0\ if\ S\ =\ 0 \\ \frac{S+1}{\sqrt{var\ (S)}}\ if\ S\ <\ 0 \end{cases}$$

The significance of the trend is assessed using the computed Z-statistics values. When the value is positive an upward (increasing) trend is followed otherwise in case of a negative value, a downward (decreasing) trend is followed.

The value of Sen's estimator test is used to identify the magnitude of the estimated trend from MK's test.This non-parametric method considers temporal series data that follows a linear trend. If X_pX_p and X_qX_q are considered as values of the time series dataset at m and n time as p > q. In that case, a positive Sen's slope value indicates rising trend while negative Sen's indicates falling trend.The slope (Q_iQ_i) is computed as:

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$$Q_i = \frac{Xp - Xq}{p - q}$$

2.3 Mapping of attributes

The methodology employed for generation of choropleth maps of area, production and productivity data of milletsfor the North Eastern Region of India (NEI) region was accomplishedthrough a series of procedural steps (Figure 2) executed using ArcMap v10.8 Geographic Information System (GIS) software. At first,the shapefile of the study area was georeferenced with thehelp of toposheet and recognized properly through Universal Transverse Mercator (UTM) anddatum [14].After that, the georeferenced shaped file was attached with the attributed dataset and the layered file was classified for creation of choropleth maps,which visually represent the spatial distribution and variations in millet area, production and productivity across the NEI region. This comprehensive mapping process allows for a detailed spatial analysis, providing insights into regional disparities and aiding in the formulation of targeted agricultural policies for the region.

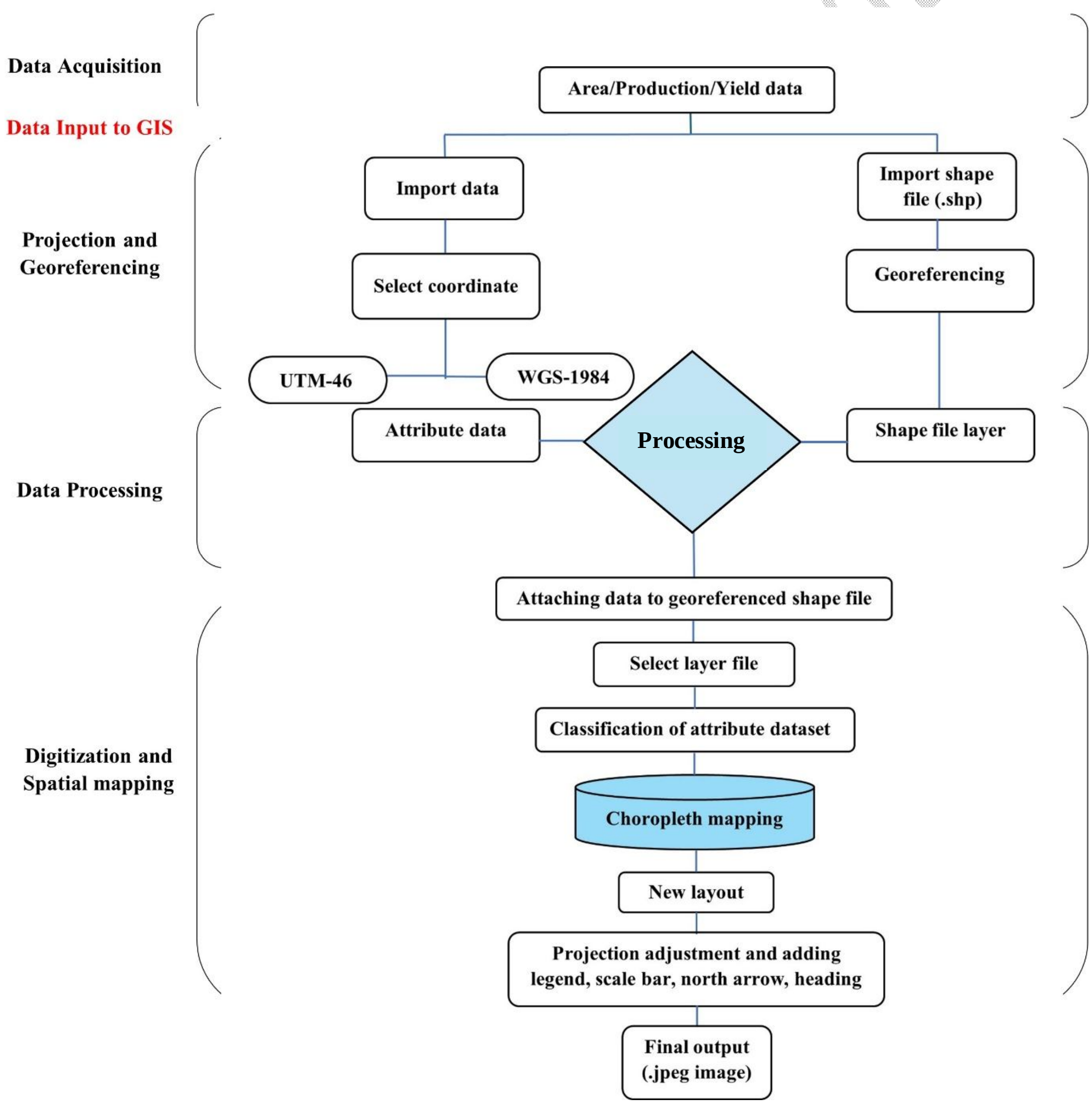

Figure 2. Plotting of choropleth map in ArcMap software

2.4Autoregressive integrated moving average (ARIMA)model

The model was first introduced by Box and Jenkins (1970) [15] for the purpose of analyzing and forecasting of univariate time series data. The ARIMA model is characterized by the notation ARIMA (*p, d, q*) where *p, d* and *q* denote the orders of auto-regression, integration (differentiation) and moving average, respectively.The auto-regressive process of the order (*p*) is computed as:

$$Y_t = c + \varphi_1 Y_{(t-1)} + \varphi_2 Y_{(t-2)} + \ldots\ldots\ldots\ldots\ldots\ldots \varphi_p Y_{(t-p)} + \varepsilon_t$$

Moving average process of order (q) is computed as:

$$Y_t = \mu - \theta_1 \varepsilon_{(t-1)} + \theta_2 \varepsilon_{(t-2)} + \ldots\ldots\ldots\ldots\ldots\ldots \theta_q \varepsilon_{(t-q)} + \varepsilon_t$$

And the general form of ARIMA model of order (p,d,q) is:

$$Y_t = \mu + \varphi_1 Y_{(t-1)} + \varphi_2 Y_{(t-2)} + \ldots \Phi_p Y_{(t-p)} + \varepsilon_t - \theta_1 \varepsilon_{(t-1)} - \theta_2 \varepsilon_{(t-2)} - \ldots \theta_q \varepsilon_{(t-q)} + \varepsilon_t$$

Where, Y_t = The value of the time series at time t; c = constant; φ_1, φ_2,…φ_p = Parameters of component; the Autoregressive; ε_{t-1}, ε_{t-2}... ε_{t-q}= Lagged forecast errors of the Moving Average component; $\theta_{1,}\theta_{2,}\ldots\theta q$ = Parameters of the Moving Average component; ε_t = White noise error term at time t.The whole methodology of Box-Jenkins process which involves parameter estimation, diagnostic checking and forecasting was done in R-studio v4.4.3 software using required plug ins.

2.5Analysis of ACF & PACF plots

Autocorrelation (ACF) and Partial Autocorrelation (PACF) plots are the graphical tools which are used in time series analysis. ACF shows the correlations between a time series and its lags while PACF displays partial correlations for intermediate lags in the time series. Significant values at certain lags indicates patterns and dependencies in the dataset.

2.6Stationarity test

The statistical test known asAugmented Dickey-Fuller (ADF)testis commonly used for determining stationarity in a time series dataset. The null hypothesis of the ADF test is that the time series possesses a unit root and is non-stationary. If the test statistic is significantly negative and falls below critical values from a table, the null hypothesis is rejected, suggesting that the time series is stationary. On the other hand, failure to reject the null hypothesis indicates that the time series is non-stationary.

2.7Ljung-Box test

It is a common test used in time series and forecasting for identifying significant autocorrelation in the residual of a fitted ARIMA model.The test helps ensure that the model adequately captures the autocorrelation structure in the data, and if there are any remaining systematic patterns in the residuals that need to be addressed. The test is designed to check

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the null hypothesis that there is no autocorrelation in the time series up to a specified lag. In our present lag order of 5 was considered for validating the best fitted ARIMA model.

3. RESULTS AND DISCUSSION

3.1Assessment of area, production and productivity status of millets

In order to accomplish the objective of the present investigation, secondary data on the area and production of millets ranging from 2000 to 2022 were used to assess long-term trends. Analysing the data will identify significant patterns, fluctuations, and changes in the area and productivity of minor millets across states of NEI. The magnitude of production trend over the period of 23 years showed an upward increasing trend of 21,500 tonnes annually (Figure 4). However, no increase in millet cultivation area has been observed in the Northeastern India (NEI) region. During the study period, the area decreased by an average of 23,000 hectares each year (Figure 3). The significant reduction in cultivated area has had a direct impact on millet production levels. From 2008 to 2019, there was no significant increase in millet production. This stagnation in production is closely related to the decreasing area under cultivation during this time period. Several factors could account for the decline in cultivated area, including changes in land use patterns, shifting agricultural practices, socioeconomic factors, and possibly a lack of adequate support for millet cultivation in the region.

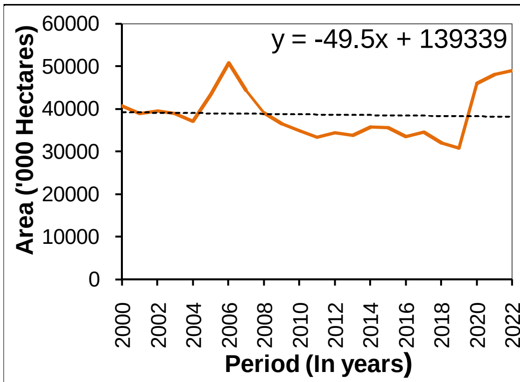

Figure3. Trend plot of area under millets (2000-2022)

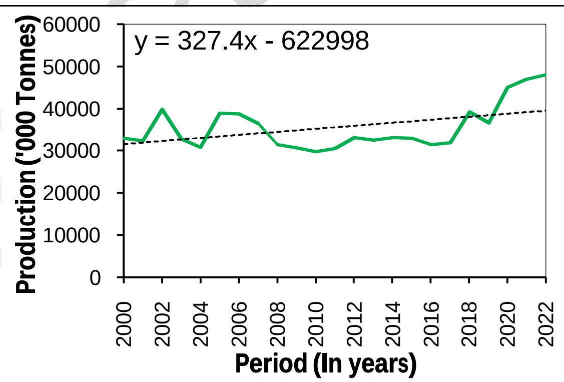

Figure4. Trend plot of production of millets (2000-2022)

The state-wise comparison of the cultivated area, production, and productivity of millets in North Eastern India from 2019 to 2022 reveals distinct trends and is depicted in Figures 5, 6 and 7. In Assam and Nagaland, there is an increasing trend in both the area under millet cultivation and the production of millets, indicating that more land is being dedicated to millet farming and that the yields are improving. Thedata suggests that either the productivity (yield per unit area) is stable or also increasing, contributing to the higher overall production. On the other hand, in Arunachal Pradesh, Meghalaya, Sikkim, and Tripura, the data shows a constant trend, implying that there have been no significant changes in the cultivated area, production, of millets in these states during this period.However, an increasing trend in productivity could be observed form the statewise yield or productivity data. From 2019 to 2022, state-wise productivity increased, with Nagaland achieving the highest productivity, followed by Sikkim. In 2021, Sikkim recorded the highest yield followed by Arunachal Pradesh, Meghalaya and Nagaland. Across the years, there was a gradual increase in yield distribution in almost all the millet growing states of North east India.This indicates that productivity has been on an upward trend, even though the area under cultivation and overall production have decreased throughout the years. This productivity boost can be attributed to several factors, including the availability of high-yielding and nutrient-rich crop varieties, pest and disease-resistant varieties, and the adoption of new climate-smart cultivation technologies.

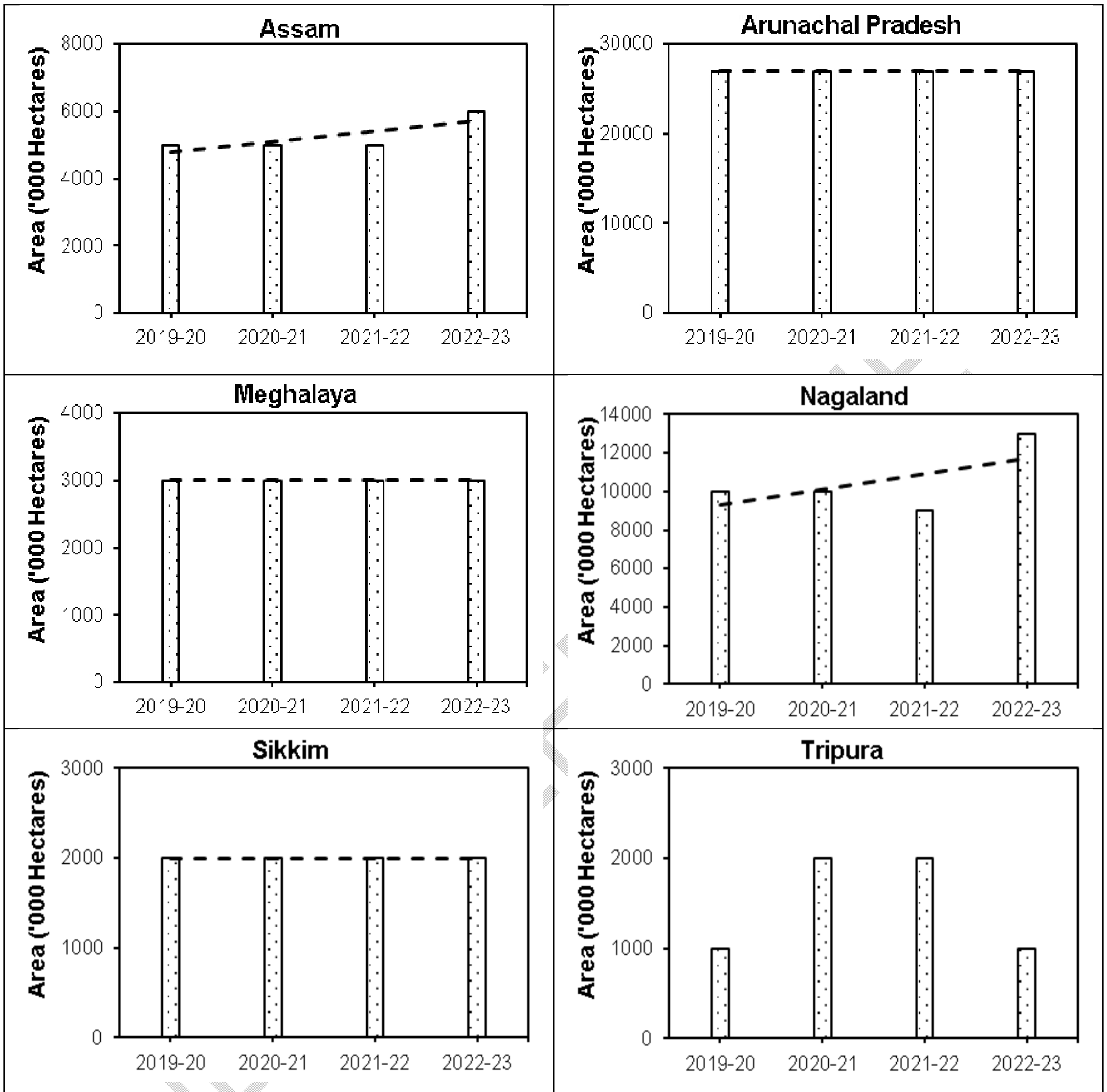

Figure5. Trend of area under millet cultivation in NEI (2019- 2022)

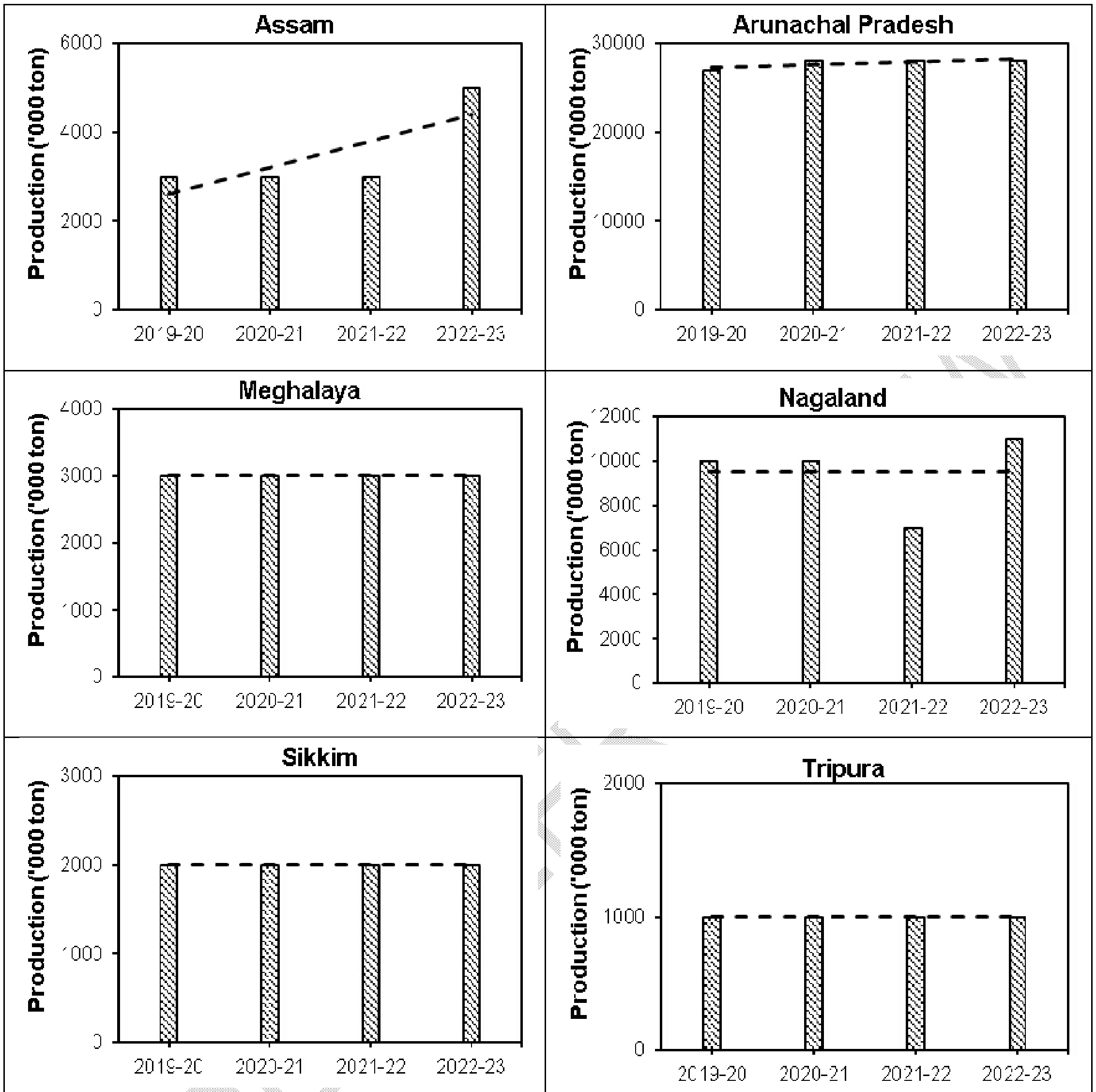

Figure6. Trend of production of millets in NEI (2019- 2022)

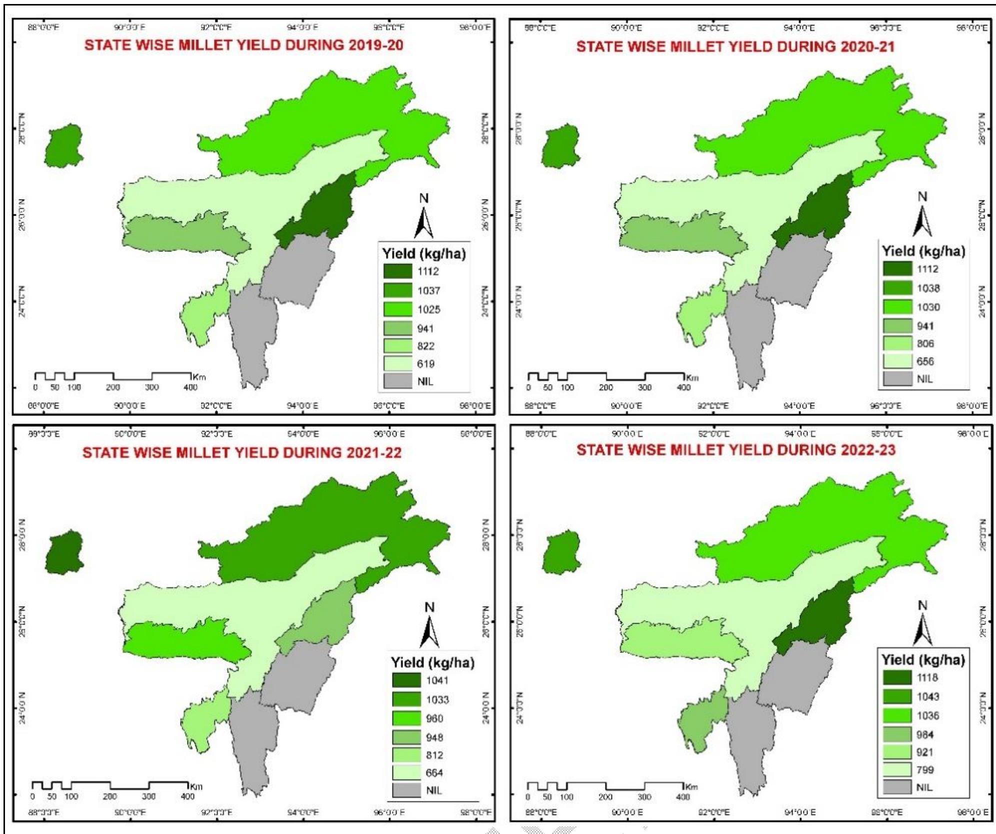

Figure7. Trend of millets productivity in NEI (2019- 2022)

The district-level data provided a better understanding of millet cultivation in Northeastern India. The cultivated area, production, and productivity values for the year 2022 were compared across all districts within the states, as illustrated in Figures 8, 9, and 10. Bongaigaon and Dhubri districts in Assam reported the highest areas under millet cultivation (Figure 8.a; 9.a), indicating these regions as key contributors to the state millet production.Arunachal Pradesh saw the Anjaw and Lohit districts with the largest areas under millet cultivation(Figure 8.b), but the highest production values were observed in the Anjaw and Longding districts(Figure9.b). This suggests that while Lohit has extensive cultivation, factors such as soil quality, farming practices, or local climate conditions may affect its yield per unit area. Understanding these factors can help devise strategies to improve productivity in Lohit.The West Garo Hills district of Meghalaya led in both the area under cultivation and millet production(Figure8.c; 9.c), highlighting it as a pivotal region for millet farming in the state. Supporting and enhancing agricultural practices in this district could significantly impact overall millet production in Meghalaya.Kohima and Phek districts in Nagaland showed the largest areas under millet cultivation(Figure 8.d), with Phek district achieving the highest production value(Figure9.d). This emphasizes the potential of Phek as a model for successful millet farming that could be replicated in other districts to boost overall productivity.East Sikkim region had the highest area under millet cultivation, suggesting that this region has favorable conditions for millet growth(Figure 8.e; 9.e). Meanwhile, Dhalai district in Tripura recorded the highest area and production value of millet(Figure 8.f; 9f), making it a crucial area for millet production in the state.These insights highlight regional variations and specific areas of high productivity, providing valuable information for policymakers and agricultural planners. By focusing on the successful practices and conditions in high-performing districts, strategies can be developed to improve millet cultivation in regions with lower productivity. Additionally, understanding the challenges and opportunities in each district can guide targeted interventions, such as introducing high-yielding varieties, improving pest and disease management, and adopting climatesmart agricultural practices. This comprehensive approach can enhance overall millet production and sustainability in Northeastern India.

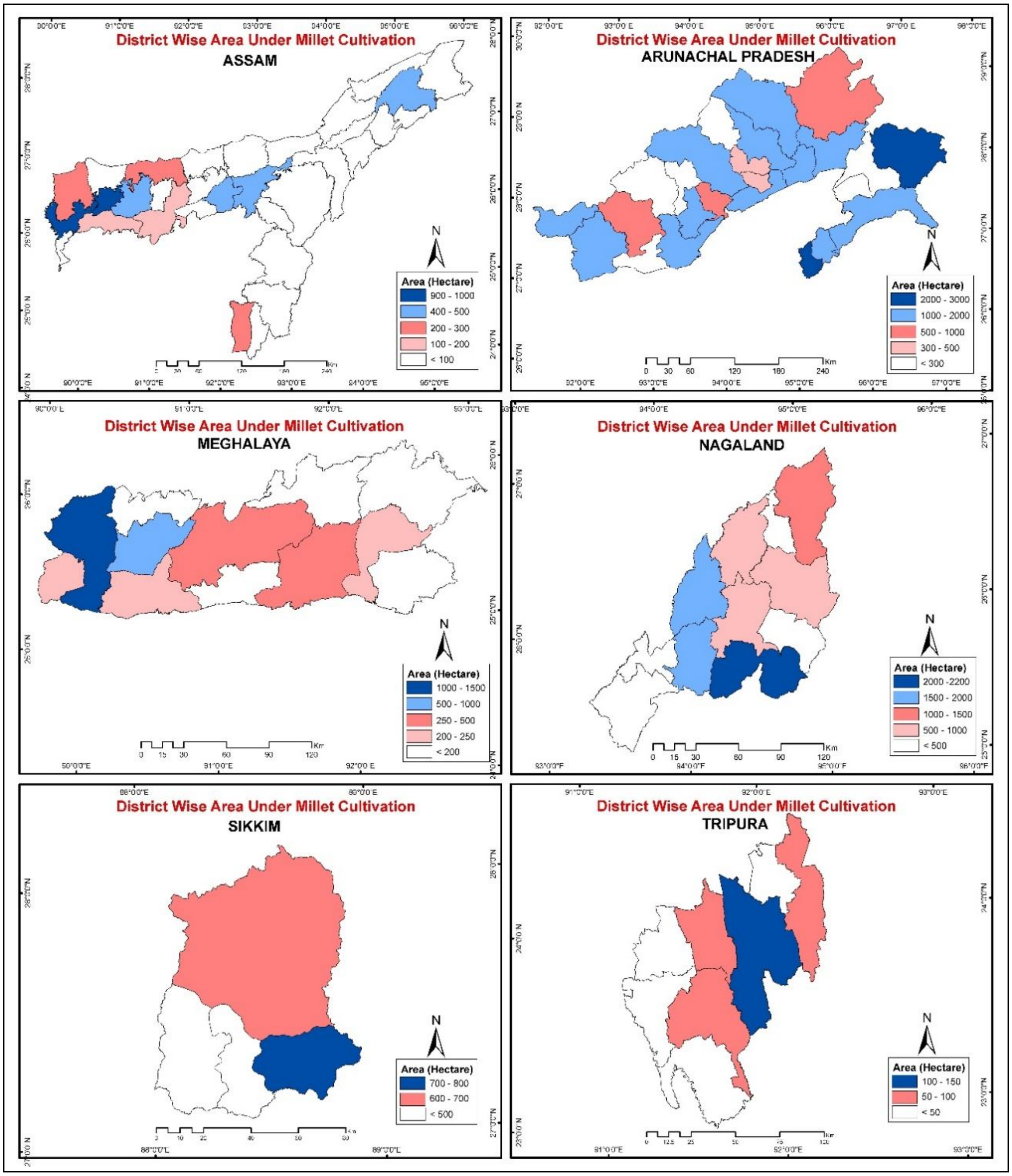

Figure8. District wise distribution of area under millets cultivation in NEI states

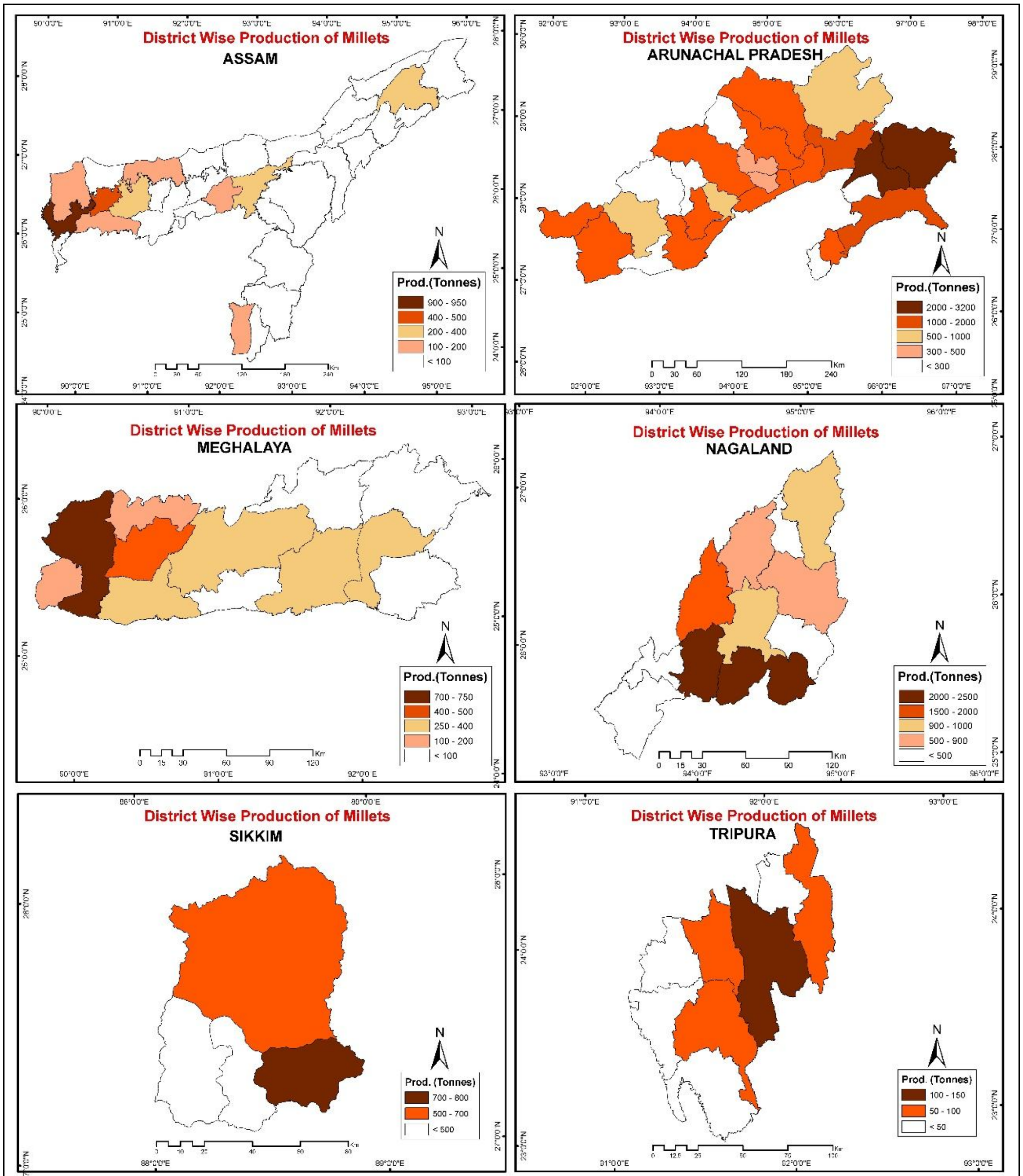

Figure9. District wise distribution of millets production in NEI states

Although the yield per unit area data varied and from that of area and production data of the districts (Figure10). In Assam, Dhubri district recorded the highest yield per unit area under millet cultivation. Likewise, Kamle district in Arunachal Pradesh, West Khasi district of Meghalaya, Paren district of Nagaland, East Sikkim district of Sikkim and Unokoti district of Tripura recorded the highest yield. The high productivity highlights the effectiveness of intensive agricultural practices and efficient use of available resources. These districts likely benefit from focused efforts in soil management, water utilization, and adoption of improved crop varieties. Additionally, local agricultural extension services and farmer training programs may play crucial roles in enhancing productivity. The success of these districts underscores the importance of tailored agricultural strategies that consider local conditions and resources.

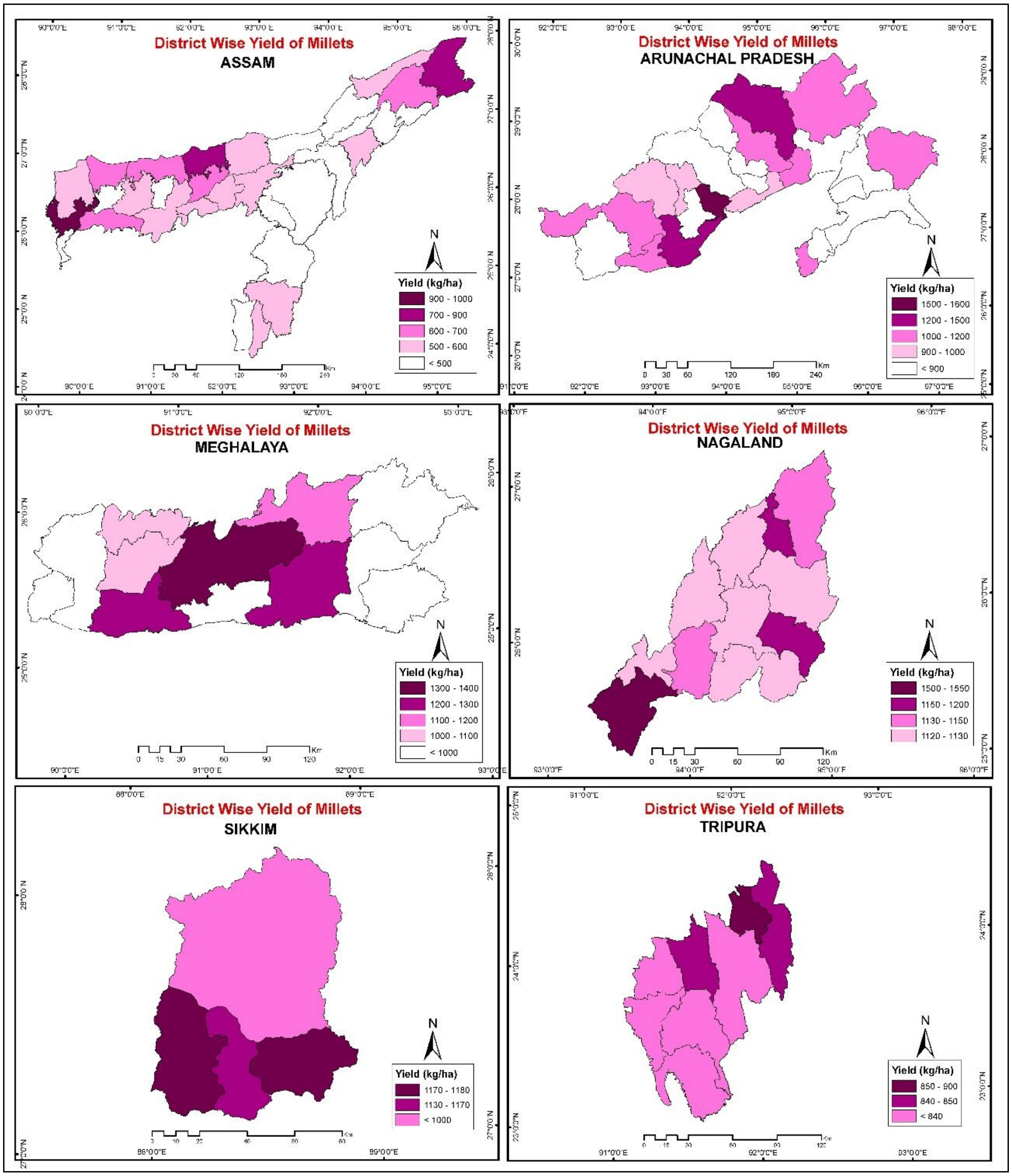

Figure10. District wise distribution of millets productivity in NEI states

3.2 Identification of best-fit ARIMA model for NEI

The first step in time series modeling is to ensure that the data is stationary, as accurate estimation is only possible with stationary series. A stationary time series has a constant mean, variance, and autocorrelation over time. There are several methods to determine if a time series is stationary. The most common method is to visually examine the data graph or time plot.Figure 11, for instance, shows that the time series data for pearl millet production and prices are non-stationary. This visual inspection reveals trends or patterns that suggest variability in mean and variance over time, indicating non-stationarity.

3.2.1 Augmented Dickey-Fuller Test

The stationarity of time series data is essential for accurate modeling, while visual inspection of plots can suggest non-stationarity through observable trends and patterns, a more objective method is the Augmented Dickey-Fuller (ADF) test. The ADF test statistically assesses whether a unit root is present, with a low p-value indicating stationarity. By using both visual tools and the ADF test, we can reliably determine if the series is stationary and suitable for further analysis. The results of ADF are depicted in Table 1.

Table 1:Results of Augmented Dickey-Fuller Test

Model Variables	Dickey-Fuller	Lag Order	P-value
Area	-1.42	2	0.7933
Production	-3.32	4	0.0718

Since the p-value is less than the critical value at 95 % level in both the cases, so there was evidence which means that we failed to reject null hypothesis and conclude that the time series formillet area and production were non-stationary. Stationary could be achieved mostly by differencing the time seriesIn essence, any attempt to use the non-stationary variables at their levels could lead to spurious regression and the result cannot be used for prediction in the long–run [16].

3.2.2 Analysis of ACF and PACF plots

The correlation between time series observations was done using Autocorreraltion function (ACF) and Partial Autocorrelation function (PACF) plots [Figure 11 (a, b, c & d). It can be seen from the figure11. (a) that the auto-correlation function (ACF) declined very slowly from 0.85 to -0.38 in the case of areaunder millet cultivation and 1.0 to -0.5 in the case of production of millet. And as some of the ACFs were significantly different from zero and fell outside the 95 percent confidence interval. All the series shows changes over time with constant mean and variance, indicating that it is not stationary. So, from these, we can conclude that the time series of area and production of millet were non-stationary and also contain autocorrelation. Appropriate differencing was needed to convert the time series into stationary. The function auto.arima() in the forecast library of RStudio was worked out and was observed that the difference of order 1 was sufficient to achieve stationarity in the mean for both the cases of cultivatedarea and production.

The next step of model identification is to find values of p and q. Identification of suitable ARIMA with the lowest AIC (Akaike Information Criterion), RMSE (Root Mean Square Error), MAPE (Mean Absolute Percentage Error), BIC (Bayesian information criterion), MAE (Mean Absolute Error)values and parameter estimation for forecasting purposes which is a tedious job. It is not feasible to simply fit every potential model and choose the one with the lowest AIC, MAPE, MAE, RMSE and BIC values. So, to overcome the above barrier, the function auto.arima() (Hyndman and Khandakar, 2008)in the forecast (Hyndman, 2010) library of statistical language tool RStudio (ver. 4.2.2) was used. This function automatically checks the possible models and selects the one with the lowest error value by using appropriate

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algorithms. To use the above function, the first raw data was converted to a time-series object using t-series library in RStudio.

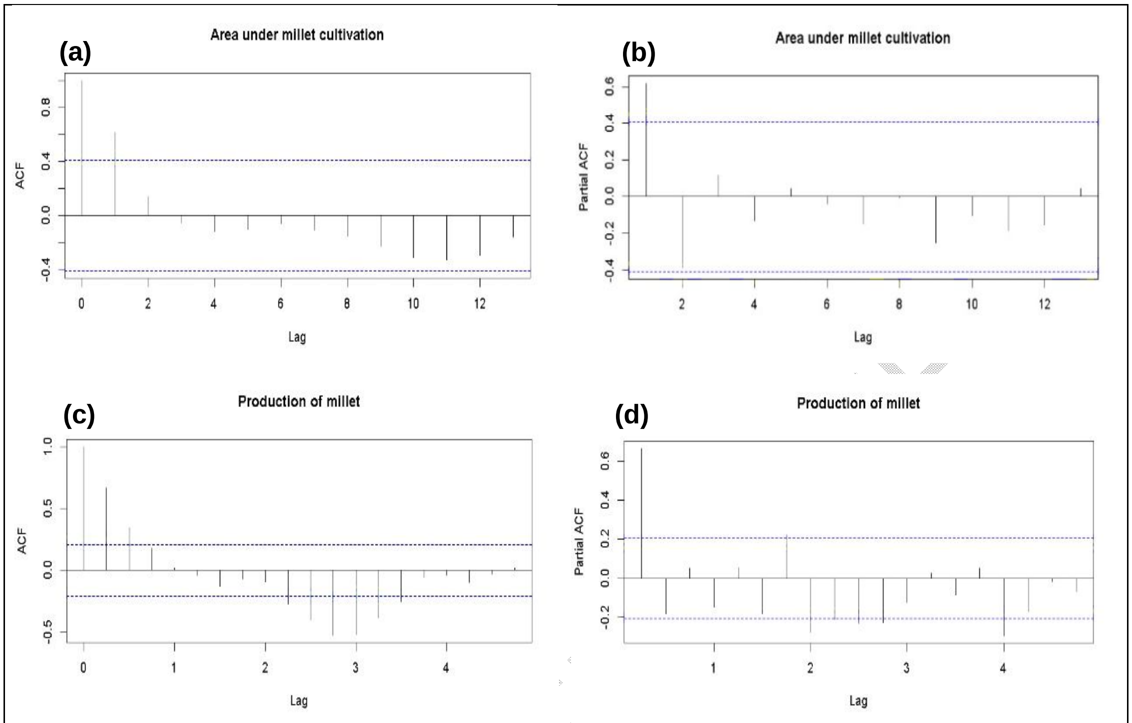

Figure11 (a, b & c, d). ACF and PACF plots of area and production of millets in NEI

3.3Model Estimation and validation

The fitted ARIMA models for forecasting the future trends in the cultivated area and production of millet in North Eastern India (NEI) were selected based on a rigorous evaluation of their performance using several statistical criteria. Specifically, models were chosen based on the lowest values of the Akaike Information Criterion (AIC), Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Bayesian Information Criterion (BIC). The values in Table 2 represents the comprehensive results of this evaluation, highlighting the models that exhibited superior performance in accurately capturing the historical data patterns and thus were deemed most suitable for forecasting purposes.

For the area under millet cultivation, the ARIMA (0, 0, 1) model emerged as the optimal choice. This model, characterized by no differencing and a simple moving average component, was found to minimize the error metrics most effectively, indicating its robustness in handling the underlying data variability. In contrast, the production of millet was best modeled using a more complex seasonal ARIMA structure, specifically ARIMA (2, 0, 1) (2, 0, 2)(2). This model incorporates autoregressive and moving average terms both at the regular and seasonal levels, capturing the more intricate patterns in the production data. The seasonal component, with a period of 2, reflects the quarterly variations inherent in millet production cycles of the NEI region. These model selections underscore the importance of tailoring the ARIMA specifications to the unique characteristics of the dataset. The ARIMA (0, 0, 1) model's simplicity was sufficient for the area data, suggesting relatively stable trends with minor short-term fluctuations. On the other hand, the more complex seasonal ARIMA model for production data indicates the presence of significant seasonal effects and long-term dependencies that necessitate a more detailed modeling approach.

Table 2: Estimation of ARIMA model filled for area and production of millets in NEI

Model Variables	Order (p, d, q)	Variance (σ^2)	AIC	BIC	RMSE	MAPE	MAE
Area	ARIMA (0, 0 ,1)	15867167	451.3	454.7	3806.2	7.4	2888.1
Production	ARIMA (2, 0, 1) (2, 0, 2) (2)	9350312	1696.4	1718.8	2917.2	6.0	2184.4

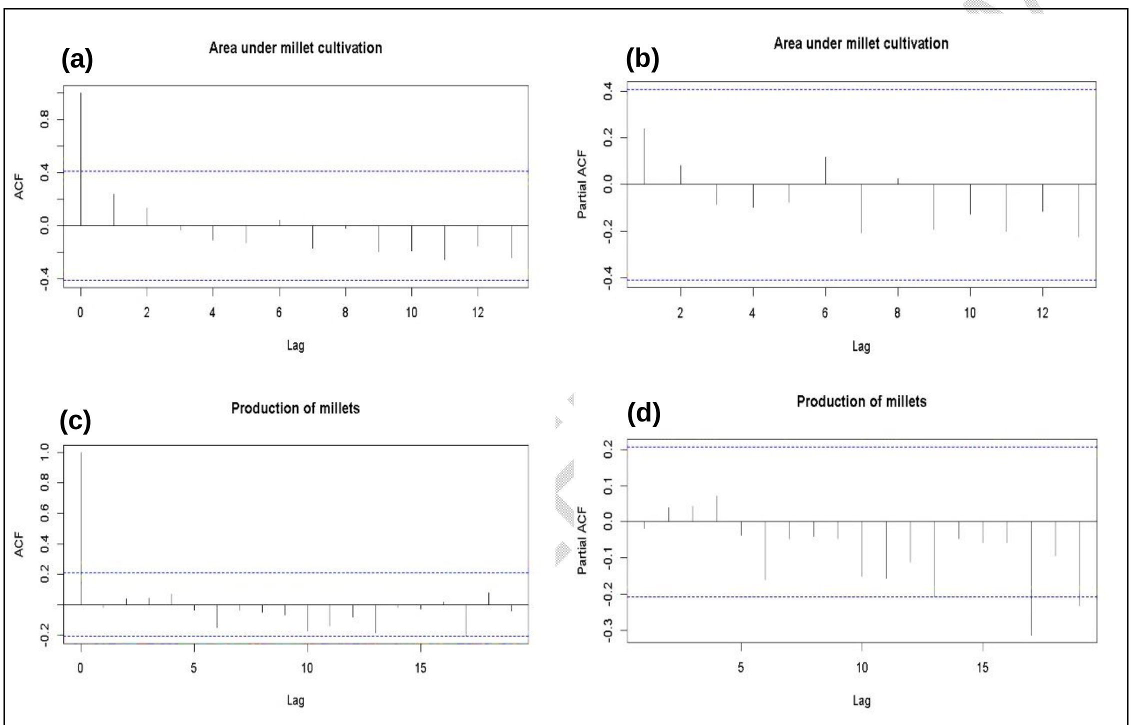

Figure12 (a, b & c, d). ACF and PACF plots of ARIMA (0, 0 ,1) and ARIMA (2,0,1)(2,0, 2)(2)

The autocorrelation function (ACF) and partial autocorrelation function (PACF) plots of area and production [Fig. 12 (a, b, c & d)] after the conversion of the time series data from non-stationary to stationary data following the auto.arima () function shows that the ACF and PACF coefficient between lags do not violates the significant bounds compared to before differencing time series data into stationary level. This result indicates that the fitted ARIMA models for both the variables found no non-zero autocorrelations in the forecast residuals.

3.3.1 Ljung-Box test (Diagnostic test)

Further the fitted models undergo Ljung-Box test or diagnostic test for further checking of any systematic pattern in the residuals of the models which could be removed for appropriated forecasting. The test statistics are provided in Table 3.

Table 3: Test statistics of Ljung-Box test (diagnostic test)

Model Variables	Fitted model	Ljung-Box Q values		
		Statistics (x^2)	Degrees of freedom (DF)	Significance (P-value)
Area	ARIMA (0, 0 ,1)	0.89	5	0.97
Production	ARIMA (2, 0, 1) (2, 0, 2) (2)	0.93	5	0.96

Since it was observed that the p-value is greater than the significance level (0.05), the models failed to reject the null hypothesis and concluded that there is no significant autocorrelation in the residuals in the two variables. The values indicate that there are no systematic patterns observed in case of both the fitted model. Thus, validating the fitted model for further forecasting.

3.4Forecasting

The fitted model after validation were used for forecasting of cultivated area and production of millets for the entire North Eastern India (NEI) region for the next 3 years (2022-23 to 2025-26). Results of the millet cultivated area and production forecasted values along with upper and lower limit are shown in Figures 13 and 14. ARIMA (0, 0 ,1) was utilized to estimate the 3-year advance cultivated area projection and the results were plotted with 95 per cent confidence level in Figure 13. According to the current trend of area under millet cultivation, it is projected that the area will experience an increase of approximately 20.3 percent by the year 2025-26.On the basis of the data provided by the model, the area under millet cultivation in the NEI region will increase from 49 thousand hectares in the fiscal year 2021-22 to 53 thousand hectares by the end of the fiscal year 2025-26.The projected area was forecasted to increase, ranging between an average lower limit of 45 thousand hectares and an upper limit of 57 thousand hectares. This projected range reflects uncertainties in agricultural conditions, including extreme climate uncertainties, soil conditions and agricultural practices. The ARIMA model's confidence interval ensures the forecast's robustness and reliability. The future trend in production of millet in the region was projected using the ARIMA (2, 0, 1) (2, 0, 2) (2) and the results were plotted in Figure 14. Based on the data provided by the model it was observed that the production of millet will increase by 26.7 per cent for the millet growing states of the North Eastern India region. The production will experience an upward increasing trend from 48 thousand tonnes in the fiscal year 2021-22 to 53 thousand tonnes in the fiscal year 2025-26. In case of production of millet,the projection trough fitted ARIMA model showed the increase in production values between an average lower limit of 43 thousand tonnes and an upper limit of58 thousand tonnes.These results align with the findings on the past trends and forecasting in cultivated area, production and yield of pearl millet in India using ARIMA model [17].

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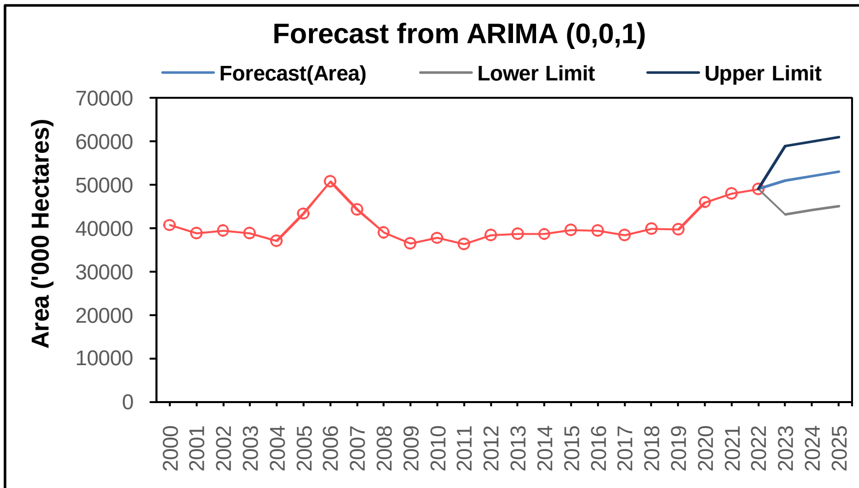

Fig. 13. Forecast of area under millets cultivation in NEI

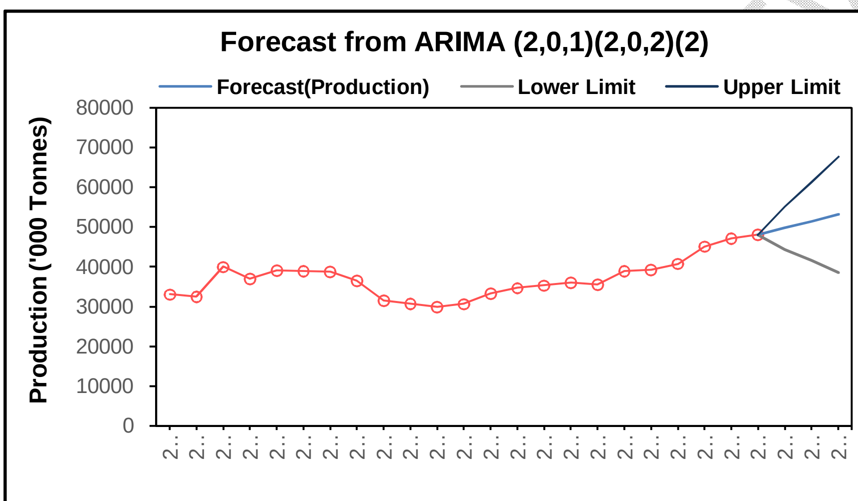

Fig. 14. Forecast of millets production in NEI

4. CONCLUSION

The investigation into the trends and forecasting of millet cultivation in North Eastern India (NEI) using ARIMA models has revealed critical insights. Utilizing secondary data from 2000 to 2022, the study identified significant declines in the cultivated area, averaging a decrease of 23,000 hectares annually, contrasted by an increasing production trend of 21,500 tonnes per year. State-wise and district-level analyses highlighted regional variations, with some areas showing improvements in yield despite the overall reduction in cultivated area. The ARIMA (0, 0, 1) model was optimal for forecasting the cultivated area, while a more complex ARIMA (2, 0, 1)(2, 0, 2)(2) model suited production data, both were selected based on the lowest AIC, MAPE, MAE, RMSE, and BIC values. The fitted models, validated through diagnostic tests, projected a 20.3 per cent increase in cultivation area and a 26.7 per cent rise in production by 2025-26, emphasizing the need for targeted agricultural strategies to enhance millet production sustainably across NEI.While the past trend shows a decline in the area under millet cultivation, the future projection shows an increasing trend, possibly due to the rising importance of nutrient-rich, gluten-free millets over cereal crops. This shift can be attributed to the availability of high-yielding, pest and disease-resistant varieties, and improved cultivation practices. Forecasted production will assist the government in encouraging export promotion by providing incentives, improving trade facilitation, and exploring new markets. These forecasts will aid farmers, traders, and policymakers in making informed decisions regarding production, marketing, and policy interventions of millets in the North eastern states of India.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

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