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# GROWTH PATTERNS OF MILLET PRODUCTION IN KARNATAKA : A STATISTICAL APPROACH

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**ABSTRACT**

Agriculture plays a crucial role in the Indian economy. Millets, small-seeded annual grasses known as Nutri-Cereals, are rich in micronutrients like iron, zinc, and calcium. Their climate resilience and low glycemic index make them ideal for cultivation in dry, marginal lands. In recognition of their benefits, the Indian government proposed 2023 as the International Year of Millets (IYOM) to the United Nations. This study focuses on the trend analysis of area and production of millets in Karnataka from 2006-07 to 2021-22, using secondary data from the District Statistical Office, Dharwad, and the Directorate of Economics and Statistics, Bangalore. A trend analysis for the area and production of millets in Karnataka was conducted using a variety of linear and non-linear models, including Linear, Logarithmic, Quadratic, Cubic, Inverse, Power, S-curve, and Exponential models. The cubic model provided the best fit for most millet areas and production, except for little millet area, where the inverse model was more accurate. Sorghum showed a significant negative Compound Annual Growth Rate (CAGR) for both area and production, while pearl millet, finger millet, and little millet exhibited significant negative CAGR for area. Small millets demonstrated a positive significant CAGR for production, though foxtail millet had a negative nonsignificant CAGR for area and a positive nonsignificant CAGR for production. Among all millets, finger millet showed the highest stability in both area and production, highlighting its resilience.
***Keywords*** **:** Millets, Linear model, Non-linear models, CAGR, CDVI

## Introduction

Millets, small-seeded annual grasses from the Poaceae family, are primarily cultivated as grain crops on marginal lands in arid regions. These hardy crops are uniquely positioned to address future challenges related to food security, energy, malnutrition, health, and climate change. In India, 95% of millet cultivation consists of finger millet, sorghum, and pearl millet, while the remaining 5% includes lesser-known varieties such as little millet, kodo millet, foxtail millet, proso millet, and barnyard millet (Millet Advisor, 2024).

In the arid districts of Karnataka, such as Chitradurga, Dharwad, Tumkur, Chamarajanagar, Mandya, and Raichur, farmlands are predominantly cultivated with small millet crops like Foxtail Millet, Brown Top Millet, Little Millet, Kodo Millet, Barnyard Millet, and Finger Millet. These hardy crops thrive in regions receiving less than 350 mm of rainfall and have a short growth cycle, maturing within 70 to 100 days. Although Karnataka's average annual rainfall is around 1,248 mm, these districts typically experience lower rainfall, ranging from 600 to 900 mm. Summer temperatures in these areas can fluctuate between 10 and 45 degrees Celsius (Hiren Kumar Bose, 2018).

Millets, commonly referred to as Nutri-Cereals, are highly nutritious grains that have served as a staple food for centuries. Known for their outstanding dietary benefits, including a low glycemic index and rich micronutrient content, millets are particularly well-suited to thrive in dry, marginal lands. They provide an abundance of essential nutrients like iron, zinc, and calcium, while also demonstrating resilience in the face of climate change. In recognition of their importance, the Indian government recommended that the United Nations declare 2023 as the "International Year of Millets" (IYOM). With the support of seventy-two countries, the United Nations General Assembly (UNGA) officially proclaimed 2023 as the "International Year of Millets" on March 5, 2021.

## Materials and Methods

Karnataka is divided into three main geographical regions: the Coastal Plains, the Sahyadri range, and the Deccan Plateau. The state has approximately 750 km from north to south and 400 km from east to west, covering an area of 191,796 sq. km, making it the 8th largest state in India and accounting for 5.83% of the country's total land area. Over 75% of Karnataka's land, particularly the interior, has a dry or semi-arid climate. The state contains around 15% of India's semi-arid land and 3% of its arid regions.

This study is based on secondary data regarding the area (in hectares) and production (in tons) of millets in Karnataka from 2006-07 to 2021-22. The data was sourced from the District Statistical Office in Dharwad and the Directorate of Economics and Statistics in Bangalore. The millets included in the study are finger millet, sorghum, pearl millet, little millet, kodo millet, proso millet, foxtail millet, and other small millets.

### 1. Trend analysis

**a) Linear model:** The simple linear regression model for n observations can be written as

$$Y_t = \beta_0 + \beta_1 X_1 + \varepsilon$$

Where,

$Y_t$= dependent variable (area or production),
$X_1$ = independent variable (time),
$\beta_0$ = intercept,
$\beta_1$ = coefficient to be estimated,
$\varepsilon$ = error.

**b) Quadratic model**: Here the model is

$$Y_t = \beta_0 + \beta_1 X + \beta_2 X^2 + \varepsilon$$

Where,

$Y_t$= dependent variable (area or production),
X = independent variable (time),
$\beta_0$ = intercept,
$\beta_1, \beta_2$ = coefficients to be estimated,
$\varepsilon$ = error.

**c) Cubic model:** Here model is

$$Y_t = \beta_0 + \beta_1 X + \beta_2 X^2 + \beta_3 X^3 + \varepsilon$$

Where,

$Y_t$= dependent variable (area or production),
X = independent variable (time),
$\beta_0$ = intercept,
$\beta_1, \beta_2, \beta_3$ = coefficients to be estimated,
$\varepsilon$ = error.

**d) Inverse function**

The inverse curve shows a decreasing growth, it is given by the equation:

$$Y_t = a + \frac{b}{t}$$

Where,

$Y_t$ = dependent variable (area or production),
t = independent variable (time in years),
a, b = parameters to be estimated.

The parameters can be estimated by the method of ordinary least squares.

**e) Logarithmic function**

This model shows very rapid growth, followed by slower growth, the mathematical equation is given by

$$Y_t = a + b \ln(t).$$

Where,

$Y_t$ = dependent variable (area or production),
t = independent variable (time in years),
a, b = parameters to be estimated.

The parameters can be estimated by applying the ordinary least squares approach.

**f) S- curve**

S- curve fit is given by

$$Y_t = \exp\left(a \frac{b}{t}\right) \text{ or } \ln Y_t = a + \frac{b}{t}$$

Where,

$Y_t$ = dependent variable (area or production),
t = independent variable (time in years),
a, b = parameters to be estimated.

The ordinary least squares (OLS) method can be applied to estimate the parameters of the model.

**g) Power function**

The fit is given by the equation

$$Y_t = at^b \text{ or } \ln Y_t = \ln(a) + b \ln(t).$$

Where,

$Y_t$ = dependent variable (area or production),
t = independent variable (time in years),
a, b = parameters to be estimated,

The parameters are estimated using the ordinary least square technique.

## 2. CAGR (Compound Annual Growth Rate)

Compound annual growth rate was used to study the growth rate of area and production of millets.

Before calculating the growth rate, the exponential function of millet area and production has to be estimated. i.e.,

$$Y_t = ab^t u_t$$

Where,

$Y_t$ = area, production,

a= intercept,

b= regression coefficient,

t = year which takes value 1, 2,3, …, n,

$u_t$= error term.

Logarithmic transformation was applied to the above exponential function. Hence, the estimating equation was

$$\log Y_t = \log a + t \log b + \log u_t.$$

The equation was estimated by the ordinary least square technique (OLS). The compound growth rate (g) was then estimated by the identity given in the equation

$$g = (b'-1)\ 100.$$

Where,

g = estimated compound growth rate in per cent per year and

b' = anti log of log b.

The standard error of the growth rate was estimated and tested for its significance.

## 3. Cuddy Della Valle Index (CDVI):

Cuddy Della was used to compute the degree of variation around the trend. This is used when a variable shows some trend that may be linear or non-linear. This Index first de-trends the given series and gives a clear direction about the instability. Cuddy Della Valle index detrends the coefficient of variation by using the coefficient of determination ($R^2$).

The Cuddy Della Valle index is expressed algebraically in the following estimable form:

$$\text{Cuddy Della Valle index} = CV \times \left(1 - R^2\right)^{0.5}$$

Where,

CV = Coefficient of Variation,

$R^2$ = Co-efficient of determination.

This is calculated as

$R^2$ = RSS/TSS *i.e.* ratio of explained variation to total variation,

RSS = Variation explained by explanatory variable,

TSS = Total variation.

# Results and Discussion

## 1. Trend analysis

A statistical model used to find the trends or patterns in data over time, which helps the variables in making predictions is trend analysis. In this study, an effort was made to apply various models and determine the best-fitting one for the area and production of millets in Karnataka. The selection of the best model was based on its significance, $R^2$ value, and other evaluation metrics. Simplicity was also a key factor; if a linear model proved to be highly significant, it was chosen as the best fit. This approach helps avoid overfitting, which could compromise the accuracy of future data projections.

Different linear and nonlinear models were used for the trend analysis of area and production of sorghum in Karnataka was shown in Table 1. After comparing the evaluation metrics for the models to select a suitable model cubic model was found to be the best-fitted model with significant values for the area with $R^2$ value of 0.901 and RMSE with value 23,759.76. Also cubic model was determined to be the best-fitted significant model for production with a high $R^2$ value of 0.847 and the least RMSE value of 45,741.40. The actual and the predicted values of this model is shown in Fig. 1.

**Table 1:** Comparison of models for predicting area and production of sorghum in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | β | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | -14521.5** | 0.786 | 34906.79 | -20138.2** | 0.629 | 71353.499 |
| **Logarithmic** | -92594** | 0.878 | 183754.4 | -137126** | 0.801 | 52256.73 |
| **Inverse** | 268710.3** | 0.689 | 42110.86 | 421919.1** | 0.706 | 63477.97 |
| **Quadratic ($\beta_1$)** | -37207.8** | 0.898 | 24139.56 | -68735.7** | 0.841 | 46625.226 |
| **($\beta_2$)** | 1334.487** | | | 2858.674** | | |
| **Cubic ($\beta_1$)** | -47331.1** | **0.901** | **23759.76** | -90180.6** | **0.847** | **45741.40** |
| **($\beta_2$)** | 2779.066** | | | 5918.813** | | |
| **($\beta_3$)** | -56.65** | | | -120.005** | | |
| **Power** | -0.516** | 0.8096 | 35648.67 | -0.517** | 0.7882 | 54622.66 |
| **S** | 1.406** | 0.545 | 57613.54 | 1.508** | 0.573 | 85795.72 |
| **Exponential** | -0.086** | 0.8676 | 28240.65 | -0.08** | 0.7348 | 64248.58 |

Note: ** Significant at 1% * Significant at 5%

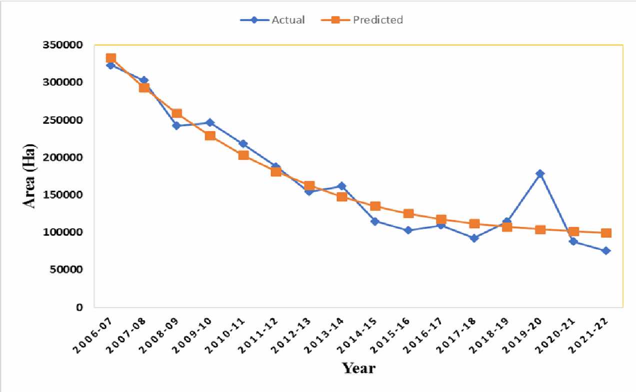


**Fig. 1(a):** Sorghum area: Cubic model

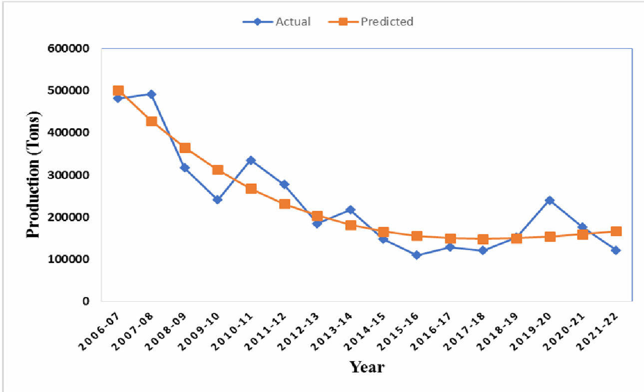


**Fig. 1(b):** Sorghum Production: Cubic model

**Fig. 1:** Plot of the best-fitted models for the area and production of sorghum in Karnataka

The trend analysis for the area and production of pearl millet in Karnataka was found using linear and nonlinear models. The cubic model was turned out to be the most appropriate and significant best-fitted model among them in terms of both area and production with high $R^2$ and low RMSE values of 0.683, 0.226 and 44,375.67, 73,468.05 respectively as shown in Table 2. The actual and the predicted values of this model is shown in Fig. 2.

**Table 2:** Comparison of models for predicting area and production of pearl millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | β | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | -12711.6** | 0.553 | 52632.58 | -2400.831 | 0.018 | 82790.97 |
| **Logarithmic** | -83855.8** | 0.662 | 276621.5 | -29262.37 | 0.072 | 252529.2 |
| **Inverse** | 259420.1** | 0.59 | 50442.45 | 143877.37 | 0.161 | 76493.22 |
| **Quadratic ($\beta_1$)** | -32184.8** | 0.629 | 47976.66 | -22031.29 | 0.086 | 79864.38 |
| **($\beta_2$)** | 1145.48** | | | 1154.733 | | |
| **Cubic ($\beta_1$)** | -75468** | **0.683** | **44375.67** | -96361.81 | **0.226** | **73468.05** |
| **($\beta_2$)** | 7321.878** | | | 11761.494 | | |
| **($\beta_3$)** | -242.212** | | | -415.951 | | |
| **Power** | -0.297** | 0.6628 | 46073.7 | -0.111 | 0.0814 | 81553.93 |
| **S** | 0.867** | 0.468 | 55263.17 | 0.536 | 0.107 | 77191.19 |
| **Exponential** | -0.048** | 0.5906 | 50750.05 | -0.009 | 0.0189 | 84105.05 |

Note: ** Significant at 1% * Significant at 5%

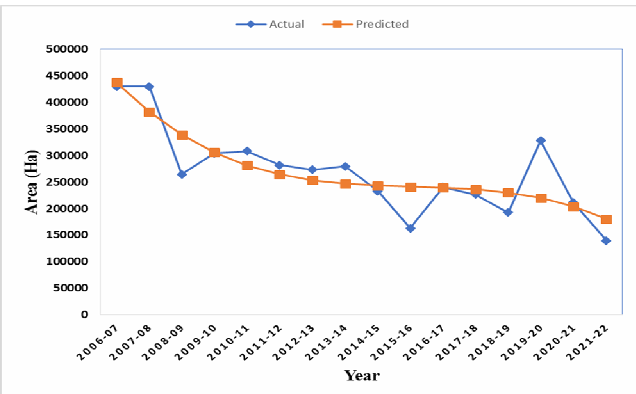


**Fig. 2(a):** Pearl millet area: Cubic model

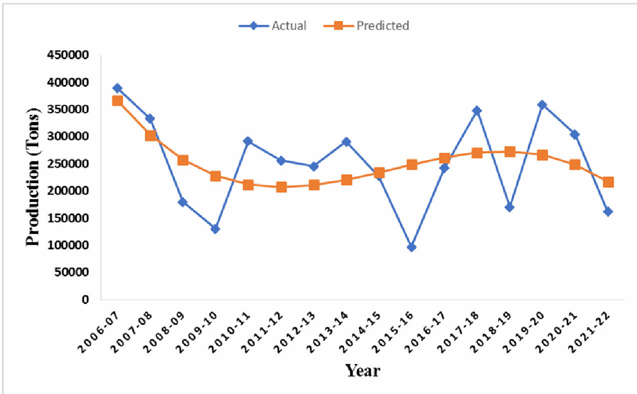


**Fig. 2(b):** Pearl millet production: Cubic model

**Fig. 2:** Plot of the best-fitted models for the area and production of pearl millet in Karnataka

Several linear and nonlinear models were used for predicting the best-fitted models for both area and production of finger millet in Karnataka was shown in Table 3. The cubic model was found to be the best-fitted significant model for trend analysis with a high $R^2$ value of 0.682 and RMSE being 50,624.88. While the cubic model was identified to be the best-fitted model but not significant for production of finger millet with $R^2$ value 0.253 and RMSE value 2,67,864.9. The actual and the predicted values of this model is shown in Fig. 3.

**Table 3:** Comparison of models for predicting area and production of finger millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | β | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | -10353.45* | 0.282 | 76096.25 | -26494.22 | 0.155 | 284883.9 |
| **Logarithmic** | -81660.83** | 0.483 | 64615.13 | -190815.4 | 0.221 | 273526.7 |
| **Inverse** | 279219.27** | 0.525 | 61880.4 | 631626.93 | 0.226 | 272730.2 |
| **Quadratic ($\beta_1$)** | -61288.31** | 0.68 | 50851.16 | -112992.1 | 0.251 | 268172.5 |
| **($\beta_2$)** | 2996.168** | | | 5088.109 | | |
| **Cubic ($\beta_1$)** | -49914.94** | **0.682** | **50624.88** | -82511.81 | **0.253** | **267864.9** |
| **($\beta_2$)** | 1373.219** | | | 738.659 | | |
| **($\beta_3$)** | 63.645** | | | 170.567 | | |
| **Power** | -0.114** | 0.4997 | 63649.8 | -0.204 | 0.229 | 278683.4 |
| **S** | 0.381** | 0.457 | 62912.82 | 0.632 | 0.135 | 282103.5 |
| **Exponential** | -0.015* | 0.3024 | 75302.36 | -0.029 | 0.1695 | 287983.7 |

Note: ** Significant at 1% * Significant at 5%

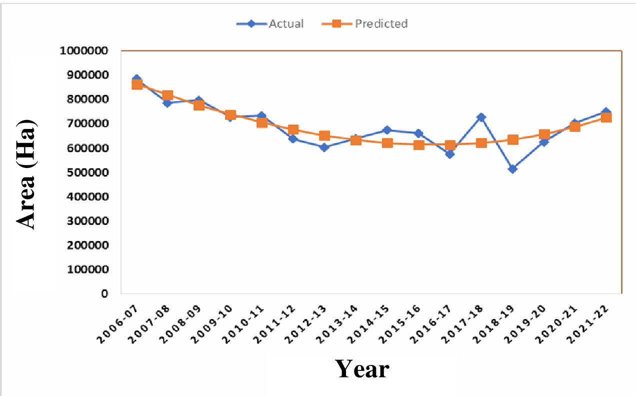


**Fig. 3(a):** Finger millet area: Cubic model

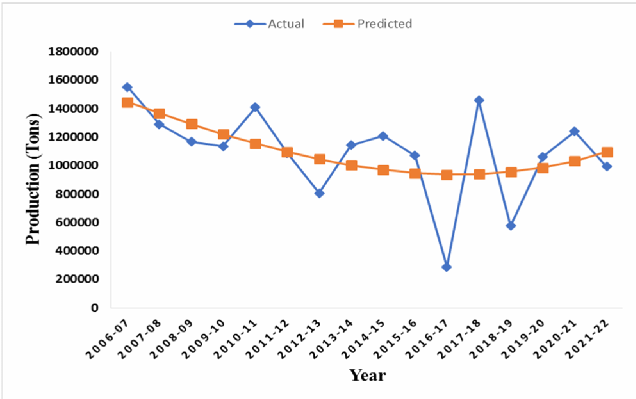


**Fig. 3(b):** Finger millet production: Cubic model

**Fig. 3:** Plot of the best-fitted models for the area and production of finger millet in Karnataka

For predicting the best-fitted model for area and production of the foxtail millet in Karnataka, different linear and nonlinear models were used as shown in Table 4. The cubic model was revealed to be the best-fitted model for both area and production but not significant with a high $R^2$ value of 0.368 and RMSE value of 6,054.291 for the area and high $R^2$ value of 0.351 and 2,437.816 being RMSE for production. The actual and the predicted values of this model is shown in Fig. 4.

**Table 4:** Comparison of models for predicting area and production of foxtail millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | β | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | -13.134 | 0.00006 | 7617.1 | 179.244 | 0.075 | 2911.562 |
| **Logarithmic** | -2022.514 | 0.041 | 7458.928 | 340.166 | 0.007 | 3015.355 |
| **Inverse** | 12282.691 | 0.141 | 7058.363 | 1372.827 | 0.011 | 3009.559 |
| **Quadratic ($\beta_1$)** | -3245.327 | 0.222 | 6716.77 | -1034.696 | 0.273 | 2580.078 |
| **($\beta_2$)** | 190.129 | | | 71.408 | | |
| **Cubic ($\beta_1$)** | -10149.062 | **0.368** | **6054.291** | -3040.046 | **0.351** | **2437.816** |
| **($\beta_2$)** | 1175.273 | | | 357.566 | | |
| **($\beta_3$)** | -38.633 | | | -11.222 | | |
| **Power** | -0.157 | 0.0558 | 7526.912 | -0.026 | 0.0064 | 3113.082 |
| **S** | 0.777 | 0.176 | 7085.273 | 0.467 | 0.044 | 3079.463 |
| **Exponential** | -0.008 | 0.0003 | 7761.286 | 0.018 | 0.0835 | 3015.942 |

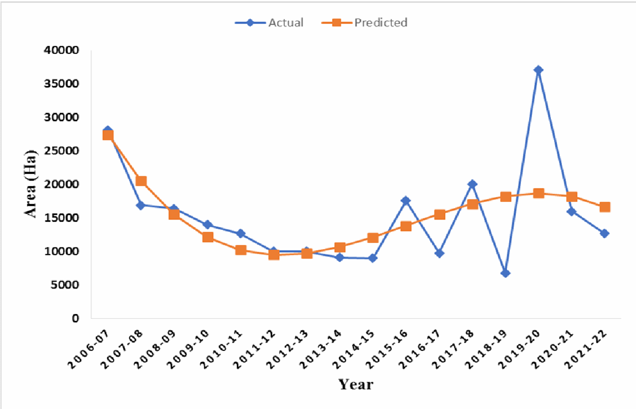


**Fig. 4(a):** Foxtail millet area: Cubic model

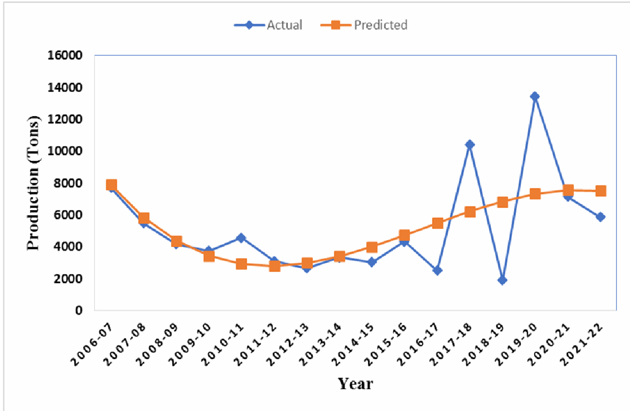


**Fig. 4(b):** Foxtail millet production: Cubic model

**Fig. 4:** Plot of the best-fitted models for the area and production of foxtail millet in Karnataka

The trend analysis for area and production of little millet in Karnataka was revealed in Table 5, using linear and nonlinear models. The inverse model was assessed to be the best-fitted significant model for the area with $R^2$ 0.706 and RMSE 1,795.109, whereas the cubic model was found to be the best-fitted model for production but not significant with high $R^2$ value 0.379 and a low RMSE value of 3,877.29. The actual and the predicted values of this model is shown in Fig. 5.

**Table 5:** Comparison of models for predicting area and production of little millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | β | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | -442.884* | 0.38 | 2608.986 | 146.574 | 0.019 | 4872.939 |
| **Logarithmic** | -3312.989** | 0.584 | 2136.969 | -426.339 | 0.004 | 4908.762 |
| **Inverse** | 11940.369** | **0.706** | **1795.109** | 5482.507 | 0.068 | 4750.541 |
| **Quadratic ($\beta_1$)** | -1514.226* | 0.509 | 2321.415 | -2029.474 | 0.261 | 4230.389 |
| **($\beta_2$)** | 63.02** | | | 128.003 | | |
| **Cubic ($\beta_1$)** | -4998.215* | 0.705 | 1798.411 | -6045.36 | **0.379** | **3877.29** |
| **($\beta_2$)** | 560.176* | | | 701.059 | | |
| **($\beta_3$)** | -19.496* | | | -22.473 | | |
| **Power** | -0.214** | 0.6268 | 2042.189 | -0.07 | 0.0068 | 4980.66 |
| **S** | 0.74** | 0.602 | 1819.663 | 0.537 | 0.097 | 4789.425 |
| **Exponential** | -0.03* | 0.4073 | 2574.566 | 0.007 | 0.0208 | 4957.526 |

Note: ** Significant at 1% * Significant at 5%

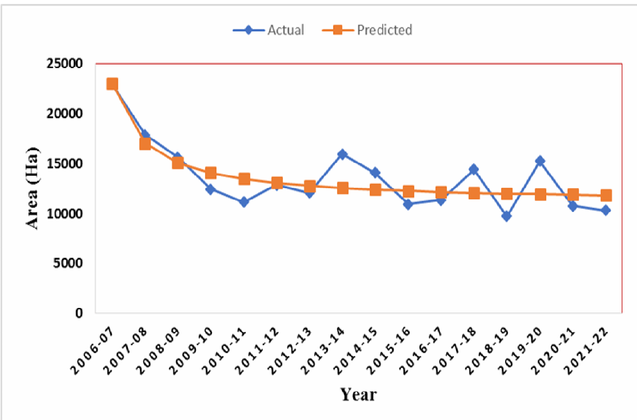


**Fig. 5(a):** Little millet area: Inverse model

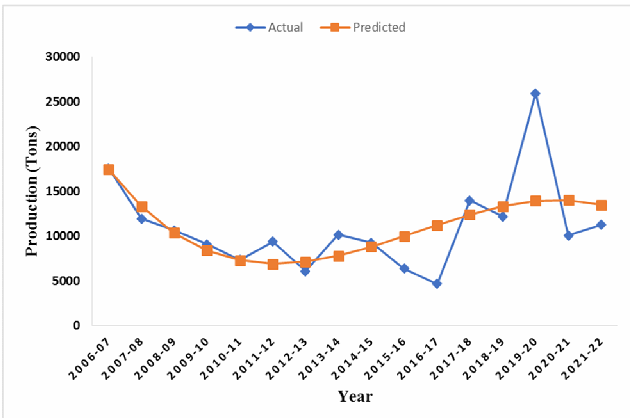


**Fig. 5(b):** Little millet production: Cubic model

**Fig. 5:** Plot of the best-fitted models for the area and production of little millet in Karnataka

**Table 6:** Comparison of models for predicting area and production of kodo millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | β | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | 16.516** | 0.4464 | 84.7846 | 9.363** | 0.544 | 39.5210 |
| **Logarithmic** | 78.129* | 0.2745 | 97.0626 | 43.283* | 0.319 | 48.2813 |
| **Inverse** | -161.448 | 0.109 | 107.4864 | -88.501 | 0.124 | 54.76321 |
| **Quadratic ($\beta_1$)** | -16.832** | 0.5522 | 76.2539 | -14.217** | 0.745 | 29.58119 |
| **($\beta_2$)** | 1.9617** | | | 1.387** | | |
| **Cubic ($\beta_1$)** | -49.586* | **0.5669** | **74.99479** | -9.59** | **0.746** | **29.51759** |
| **($\beta_2$)** | 6.6355* | | | 0.727** | | |
| **($\beta_3$)** | -0.1833* | | | 0.026** | | |

Note: ** Significant at 1% * Significant at 5%

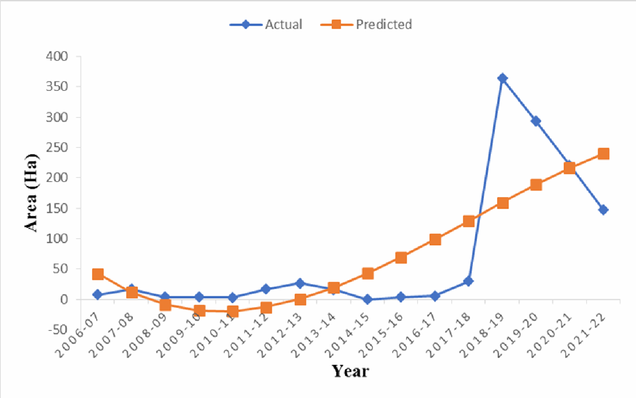


**Fig. 6(a):** Kodo millet area: Cubic model

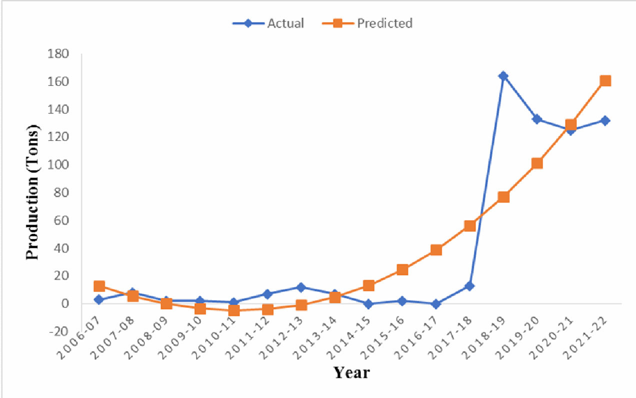


**Fig. 6(b):** Kodo millet production: Cubic model

**Fig. 6:** Plot of the best-fitted models for the area and production of other small millet in Karnataka

Several linear and nonlinear models were used to analyze the trend of kodo millet in Karnataka as depicted in Table 6. The cubic model was determined to be the significant best-fitted model for both area and production with high $R^2$ 0.5669 and 0.746 with RMSE values of 74.9949 and 29.5175. The actual and the predicted values of this model is shown in Fig. 6.

Proso millet trend analysis was exhibited in Table 7, the cubic model was turned out to be the significant best-fitted model for both area and production with $R^2$ values of 0.561 and 0.533, RMSE values being 54.3153 and 6.4844 respectively. The actual and the predicted values of this model is shown in Fig. 7.

**Table 7:** Comparison of models for predicting area and production of proso millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | B | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | 12.178** | 0.465 | 59.92204 | 1.334** | 0.42 | 7.2264 |
| **Logarithmic** | 60.171* | 0.313 | 67.9496 | 6.647* | 0.287 | 8.0144 |
| **Inverse** | -132.00 | 0.141 | 75.9693 | -14.884 | 0.134 | 8.8307 |
| **Quadratic ($\beta_1$)** | -9.158** | 0.549 | 55.0570 | -1.062* | 0.499 | 6.7179 |
| **($\beta_2$)** | 1.255** | | | 0.141* | | |
| **Cubic ($\beta_1$)** | 11.805* | **0.561** | **54.3153** | 3.11* | **0.533** | **6.4844** |
| **($\beta_2$)** | -1.736* | | | -0.454* | | |
| **($\beta_3$)** | 0.117* | | | 0.023* | | |

Note: ** Significant at 1% * Significant at 5%

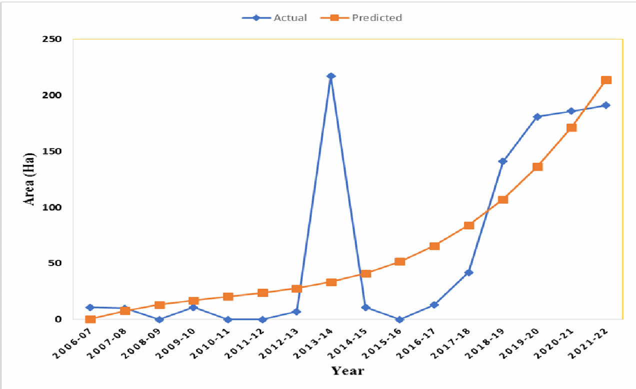


**Fig. 7(a):** Proso millet area: Cubic model

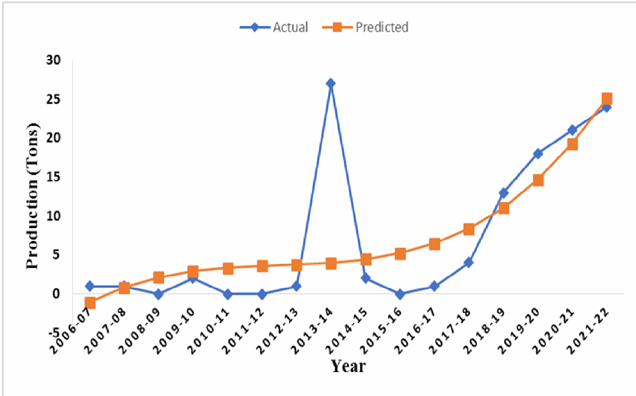


**Fig. 7(b):** Proso millet production: Cubic model

**Fig. 7:** Plot of the best-fitted models for the area and production of proso millet in Karnataka

The different linear and nonlinear models were used for analyze the trends of the other small millets in Karnataka as laid out in Table 8. The cubic model was found to be the significant best-fitted for the area with $R^2$ 0.818 and RMSE 1334.211. For the production also cubic model was found to be the best-fitted significant model with $R^2$ value of 0.875 and RMSE value of 649.1253. The actual and the predicted values of this model is shown in Fig. 8.

**Table 8:** Comparison of models for predicting area and production of other small millet in Karnataka

| Models | Area (Ha) | | | Production (Tons) | | |
|---|---|---|---|---|---|---|
| | B | $R^2$ | RMSE | β | $R^2$ | RMSE |
| **Linear** | 502.41** | 0.549 | 2098.044 | 296.301** | 0.553 | 1227.578 |
| **Logarithmic** | 2254.065* | 0.304 | 2607.528 | 1346.967* | 0.314 | 1520.951 |
| **Inverse** | -4401.817 | 0.108 | 2951.617 | -2770.587 | 0.124 | 1719.065 |
| **Quadratic ($\beta_1$)** | -940.075** | 0.812 | 1353.305 | -588.463** | 0.84 | 734.8124 |
| **($\beta_2$)** | 84.852** | | | 52.045** | | |
| **Cubic ($\beta_1$)** | -402.421** | **0.818** | **1334.211** | 228.873** | **0.875** | **649.1253** |
| **($\beta_2$)** | 8.13** | | | -64.587** | | |
| **($\beta_3$)** | 3.009** | | | 4.574** | | |
| **Power** | 0.764 | 0.4972 | 3147.271 | 1.096* | 0.5729 | 1782.018 |
| **S** | -1.1 | 0.028 | 3388.595 | -2.559 | 0.143 | 1945.626 |
| **Exponential** | 0.196* | 0.7638 | 2547.048 | 0.231** | 0.8213 | 1412.692 |

Note: ** Significant at 1% * Significant at 5%

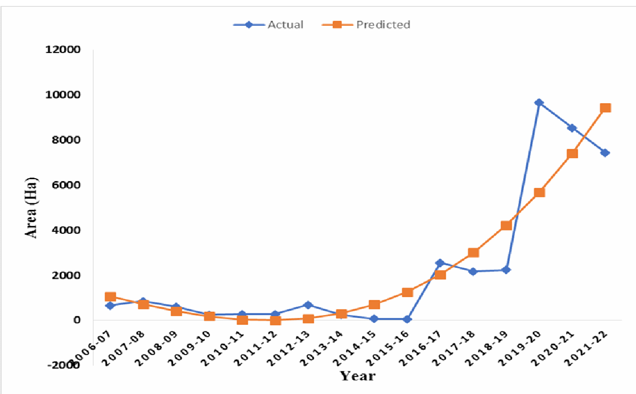


**Fig. 8(a):** Other small millet area: Cubic model

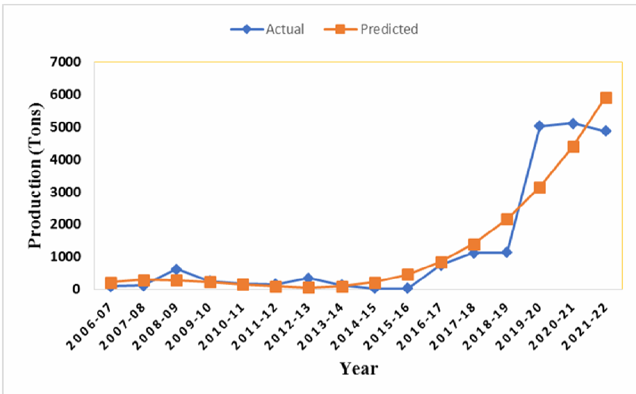


**Fig. 8(b):** Other small millet production: Cubic model

**Fig. 8:** Plot of the best-fitted models for the area and production of other small millet in Karnataka

The suitable models for area and production were shown in Table 9 and 10 respectively. Overall cubic model was found to be the best-fitted model for both the area and production of millets in Karnataka. With high value of $R^2$ and low values of RMSE were used for the performance metrics of the model.

**Table 9:** Suitable models for the area of millets in Karnataka

| Crop | Best Model | Equation | $R^2$ |
|---|---|---|---|
| **Sorghum** | Cubic | $Y = 377548.876 - 47331.144^{**}X + 2779.066^{**} X^2 - 56.650^{**} X^3$ | 0.901 |
| **Pearl Millet** | Cubic | $Y = 505979.212 – 75468.000^{**}X + 7321.878^{**} X^2 - 242.212^{**} X^3$ | 0.683 |
| **Finger Millet** | Cubic | $Y = 912690.541 - 49914.938^{**}X + 1373.219^{**} X^2 + 63.645^{**} X^3$ | 0.682 |
| **Foxtail Millet** | Cubic | $Y = 36408.547 - 10149.062^{**}X + 1175.273^{**} X^2 - 38.633^{**} X^3$ | 0.368 |
| **Little Millet** | Inverse | $Y = 11085.615 + (11940.369^{**}/X)$ | 0.706 |
| **Kodo Millet** | Cubic | $Y = 85.626 – 49.586^{*}X + 6.6355^{*}X^2 - 0.1833^{*}X^3$ | 0.566 |
| **Proso Millet** | Cubic | $Y = -9.794 + 11.805^{*}X - 1.736^{*} X^2 + 0.117^{*} X^3$ | 0.561 |
| **Other Small Millets** | Cubic | $Y = 1469.527 - 402.421^{**}X + 8.130^{**} X^2 + 3.009^{**} X^3$ | 0.818 |

Note: ** Significant at 1% * Significant at 5%

**Table 10:** Suitable models for the production of millets in Karnataka

| Crop | Best Model | Equation | $R^2$ |
|---|---|---|---|
| **Sorghum** | Cubic | $Y = 586059.885 - 90180.644^{**}X – 5918.813^{**}X^2 – 120.005^{**}X^3$ | 0.847 |
| **Pearl Millet** | Cubic | $Y = 451754.706 – 96361.807X + 11761.494 X^2 – 415.951 X^3$ | 0.226 |
| **Finger Millet** | Cubic | $Y = 1528209.635 – 82511.811X + 738.659 X^2 + 170.567 X^3$ | 0.253 |
| **Foxtail Millet** | Cubic | $Y = 10593.821 - 3040.046X + 357.566 X^2 - 11.222 X^3$ | 0.351 |
| **Little Millet** | Cubic | $Y = 22804.104 - 6045.360X + 701.059 X^2 - 22.473 X^3$ | 0.379 |
| **Kodo Millet** | Cubic | $Y = 21.813 – 9.590^{**}X + 0.727^{**} X^2 + 0.026^{**} X^3$ | 0.746 |
| **Proso Millet** | Cubic | $Y = -3.75 + 3.1104^{*}X - 0.4545^{*}X^2 + 0.0233^{*}X^3$ | 0.533 |
| **Other Small Millets** | Cubic | $Y = 56.569 + 228.873^{**}X - 64.587^{**} X^2 + 4.574^{**} X^3$ | 0.875 |

Note: ** Significant at 1% * Significant at 5%

The study analyzing sorghum in Karnataka found that the cubic model was the best-fitting and highly significant model for both area and production, with high $R^2$ values of 0.90 and 0.84, and low RMSE values, as shown in Table 1. Similarly, for pearl millet, various linear and nonlinear models were applied, and the cubic model emerged as the best-fitting and highly significant model for the area, with an $R^2$ of 0.68 and low RMSE. However, for production, although the cubic model was the best fit, it was not significant, with an $R^2$ of 0.22 and low RMSE, as shown in Table 2. For finger millet, the cubic model was identified as the best-fitting and highly significant model for the area, with an $R^2$ of 0.68 and low RMSE, while for production, although the cubic model was the best fit, it was not significant, with an $R^2$ of 0.25 and low RMSE, as detailed in Table 3. In the case of foxtail millet, the cubic model was the best-fitting but non-significant model for both area and production, with $R^2$ values of 0.368 and 0.351, and low RMSE values, as seen in Table 4.

For little millet, the inverse model was found to be the best-fitting and highly significant model for the area, with an $R^2$ of 0.70 and low RMSE, while the cubic model, although the best fit for production, was non-significant, with an $R^2$ of 0.37 and low RMSE, as shown in Table 5. Table 6 indicated that for kodo millet, the cubic model was the best-fitting and highly significant model for both area and production, with $R^2$ values of 0.56 and 0.74, and low RMSE. In predicting the area and production of proso millet, the cubic model was found to be the best-fitting and highly significant model for both parameters, with $R^2$ values of 0.56 and 0.53, as seen in Table 7. Lastly, the cubic model was identified as the best-fitting and highly significant model for predicting the area and production of other small millets in Karnataka, with high $R^2$ values of 0.81 and 0.87, and low RMSE, as detailed in Table 8.

## 2. Compound annual growth rate

The compound annual growth rate was used to find the trend over the period of 16 years from 2006-07 to 2021-22. The area of sorghum, pearl millet, finger millet, and little millet were found to have negative significant growth rate of 3.66(%), 2.05(%), 0.633(%), and 1.29(%). The foxtail millet area was found to have negative growth rate of 0.35(%). Whereas other small millets area was determined to be a positive significant growth rate of 8.90(%) as shown in Table 11.

**Table 11:** Growth rate of area of millet based on CAGR(%) in Karnataka

| | Sorghum | Pearl Millet | Finger Millet | Foxtail Millet | Little Millet | Kodo Millet | Proso Millet | Other Small Millets |
|---|---|---|---|---|---|---|---|---|
| CAGR | -3.66418** | -2.05244** | -0.633** | -0.35405 | -1.29264** | - | - | 8.904464* |

**Note**: ** Significant at 1% * Significant at 5%

It was revealed from Table 12 that sorghum production had significantly negative growth rate of 3.39(%). The pearl millet and finger millet production were found to have negative growth rates of 0.40(%) and 1.26(%) but not significant. Whereas the foxtail millet and little millet production was found to be positive with a growth rate of 0.78(%) and 0.29(%), while the other small millet production was assessed to be a significant positive growth rate of 10.53(%).

**Table 12:** Growth rate of production of millet based on CAGR(%) in Karnataka

| | Sorghum | Pearl Millet | Finger Millet | Foxtail Millet | Little Millet | Kodo Millet | Proso Millet | Other Small Millets |
|---|---|---|---|---|---|---|---|---|
| CAGR | -3.39424** | -0.40652 | -1.26035 | 0.783584 | 0.292129 | - | - | 10.53728** |

**Note**: ** Significant at 1% * Significant at 5%

The CAGR was used to find the growth over time. The CAGR was turned out to be negative and highly significant for sorghum (3.66%), pearl millet (2.05%), finger millet (0.63%), and little millet (1.29%), whereas other small millet was positively significant with CAGR of 8.9 per cent for the area of millet in Karnataka as exhibited in Table 11. For production, sorghum had a negative significant CAGR (3.39%) and other small millet was significant with a positive CAGR (10.53%) as depicted in Table 12.

A similar finding was reported by Kumar *et al.* (2022), who conducted a trend analysis of the area, production, and productivity of minor millets in India from 1990-91 to 2019-20. The secondary data for the study, covering the area, production, and productivity of minor millets, was sourced from India stat.com. The analysis utilized descriptive statistics and the compound annual growth rate. The study revealed that while the area and production of minor millets have been declining, their productivity has seen a significant increase.

### 3. Instability index

Cuddy Della Valle Index was used to measure the instability as shown in Table 13. Finger millet has instability of 11.53 per cent, little millet at 19.71 per cent, pearl millet at 20.17 per cent, sorghum at 20.77 per cent, foxtail millet at 50.99 per cent, and other small millets at 113.49 per cent concerning area. Whereas for production instability of finger millet was 27.58 per cent, sorghum at 31.71 per cent, pearl millet at 34.07 per cent, little millet at 46.09 per cent, foxtail millet at 59.18 per cent, and other small millets at 112.21 per cent as shown in Table 14.

**Table 13:** Instability analysis of area of millet based on CDVI in Karnataka

| | Sorghum | Pearl Millet | Finger Millet | Foxtail Millet | Little Millet | Kodo Millet | Proso Millet | Other Small Millets |
|---|---|---|---|---|---|---|---|---|
| CDVI | 20.77601 | 20.17986 | 11.53532 | 50.99177 | 19.71002 | - | - | 113.4926 |

**Table 14:** Instability analysis of production of millet based on CDVI in Karnataka

| | Sorghum | Pearl Millet | Finger Millet | Foxtail Millet | Little Millet | Kodo Millet | Proso Millet | Other Small Millets |
|---|---|---|---|---|---|---|---|---|
| CDVI | 31.71265 | 34.07463 | 27.58255 | 59.18367 | 46.0981 | - | - | 112.2147 |

The CDVI was used to find the instability index. From Table 13, it was found that instability for the area of finger millet (11.53%), little millet (19.71%), pearl millet (20.17%), sorghum (20.77%), and foxtail millet (50.99%), while other small millets instability was around 113.49 per cent due to huge variation in the data set. The instability for production of finger millet (27.58%), sorghum (31.71%), pearl millet (34.07%), little millet (46.09%), and foxtail millet (59.18%), meanwhile other small millets shown instability of 112.21 per cent due to huge fluctuations in the data set as showcased in the Table 14.

The study aligns with the research conducted by Vennila and Murthy (2021), which analyzed trends in the area, production, and productivity of finger millet (Ragi) in Karnataka from 2007-08 to 2018-19. This research relied on secondary data sourced from various government publications and websites, including those from the Ministry of Agriculture and Farmers Welfare, Government of India, and district-wise data from the Directorate of Economics and Statistics, Government of Karnataka. The analysis employed methods such as CAGR, CV, and Instability Index, examining these factors separately for area, production, and productivity of finger millet at the national level, as well as for Karnataka as a state and its districts. The findings revealed that the growth rate of finger millet in India exhibited a significant negative trend at the 1 per cent level, largely due to crop diversification. Production also had a significant but negative trend at the 5 per cent level, while productivity experienced an insignificant negative trend, attributed to the continued use of traditional varieties. However, the positive instability indices for area, production, and productivity suggest that finger millet cultivation poses relatively low risks.

## Conclusion

Trend analysis provides valuable insights into the patterns, shifts, and dynamics of data over a specified period, helping researchers and analysts understand historical developments. By studying the trends in key variables, such as area and production, it becomes possible to make informed predictions and decisions for future planning and resource management. In the context of the current research, the trend analysis focused on the area and production of significant millet crops in Karnataka over a span of 16 years, from 2006-07 to 2021-22.

Several statistical models, both linear and nonlinear, were considered to identify the best fit for analyzing these trends. Among these, the cubic model emerged as the most suitable for the majority of millets, effectively capturing the nuances of changes in both area and production. This model demonstrated a strong fit with high R-squared ($R^2$) values, indicating the model's ability to explain a substantial portion of the variability in the data, and low Root Mean Square Error (RMSE) values, signifying minimal deviations between the observed and predicted values. However, for little millet, the inverse model was identified as the best fit for analyzing the area under little millet cultivation, based on its superior $R^2$ and lower RMSE values compared to other models. Sorghum exhibited a significant negative Compound Annual Growth Rate (CAGR) for both area and production. Pearl millet, finger millet, and little millet also showed a significant negative CAGR for area, while other small millets displayed a significant positive CAGR for both area and production. Foxtail millet had a negative but nonsignificant CAGR for area, whereas pearl millet and finger millet showed a negative nonsignificant CAGR for production. In contrast, foxtail and little millet recorded a positive nonsignificant CAGR for production. Among all the millets, finger millet demonstrated the greatest stability in both area and production.

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