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Linear and Non-Linear Regression Techniques to Develop Predictive Models for Pearl Millet and Finger Millet Trends of Productivity in India

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Abstract:
In this study, we employed linear and non-linear regression models to determine the optimal trend for pearl millet and finger millet, considering their respective areas, production, and productivity. For this study, we have summarized the secondary annual data according to area, production, and productivity. We have used various regression models, including linear, quadratic, cubic, and logarithmic models, to determine the best trend. After analyzing these models and validating the model, we get a cubic model that shows the best trend for pearl millet area, production, and productivity with the value of coefficient of determination was 86 percentages, 60 percentages, 90 percentages for the area, production, and productivity, respectively, the value of the coefficient of determination shows how the model performed best with higher accuracy. In the finger millet crop, to get the best trend model, we found that the quadratic model and cubic model showed almost similar results, but some validation parameters showed that the cubic model was fitted. Overall, we can say the cubic model was the best for both crops.
Keywords: Pearl millet, Finger millet, Trend, Linear, and Productivity

1. INTRODUCTION

The unique agricultural products known as millet, which come from India, have become quite popular worldwide. By 2025, the demand for millet is expected to soar to an astounding $12 billion as people favor healthier grains. India is one of the world's top millet producers, with an annual production of over 12 million tons. A Sub-Mission on Nutri-Cereals is being led by the Department of Agriculture and Farmers Welfare (DA&FW) to increase the production and productivity of millets, especially Bajra [1]. With a considerable share of the world's output, India is the world's largest producer of small millets. These crops are mostly grown using rainwater, and the states that produce the most are Karnataka, Tamil Nadu, Andhra Pradesh, and Odisha. Because other staple crops are preferred, the area used for millet production has decreased over time despite its advantages. However, new projects seek to increase food and nutritional security by reviving millet production. Finger millet is commonly known as Ragi in Hindi language. In India, finger millet is commonly called by various names like ragi (in Kannada, Telugu, and Hindi), also Mandua/Mangal in Hindi belt states, Kodra in Himachal Pradesh, Mandia (Oriya), Taidalu (in Telangana Region), Kezhvaragu in Tamil, etc. India is the largest producer of finger millet in the world, India stands as a significant contributor to finger millet production, accounting for approximately 2.2 million tons, while Africa follows closely, producing about 2 million tons of finger millet (*Eleusine corcana*). https://icrisat.org/crops/finger-millet/overview. Ragi is widely cultivated and consumed in parts of Africa and Asia[1]. In India, pearl millet is an important crop that is grown on more than 8 million hectares of land. The biggest producer of pear millet is India. Therefore, the country's food security greatly depends on the production behavior and its future. The goal of this study is to determine patterns in pearl millet productivity, production, and area in India. In India, agriculture and other allied activities contribute significantly to the Gross Domestic Product (GDP), accounting for nearly 16 percent of the total GDP. It employs around 64 percent of the total workforce while contributing 18 percent of the total exports. India, with only 2.3 percent of the world's total land area, supports 18 percent of the human and 15 percent of the livestock population in the world. India has produced 10.86 million tonnes of pearl millet grain from 7.65 million hectares cultivated area [2]. More than 90 percent of pearl millet production in India is contributed by Rajasthan (38.98%), Uttar Pradesh (20.25%), Haryana (11.64%), Gujarat (10.97%), and Madhya Pradesh (9.03%) states. In the country, Rajasthan is the leading state in area and production of pearl millet, with contributions of 55.74 percent and 38.98 percent, respectively In Rajasthan, Pearl millet is cultivated in the summer (June-December) season. During 2021-22, the Jodhpur region (Jodhpur and Barmer districts) of Rajasthan covers more than 30 percent of the area of pearl millet in the state The country has made impressive progress on the food front, which has resulted in increased production of food grains. Pearl millet (*Pennisetum glaucum L.*) crop having multiple uses as food, feed, fodder, and fuels, is considered the sixth most important cereal crop after wheat, rice, maize, sorghum, and barley, Pearl millet grains keep the distinctive feature of a small seed and hardy crop which can be easily grown under marginal conditions of moisture (rainfed), less fertile soil and inputs. Its grain is the main supplier of fiber and nutritional carbohydrates in the human diet in the western part of India. Pearl millet or Bajra (*Pennisettum typhoides*) is widely grown in Africa, Asia, China, and the Russian Federation, and can be used as either grain or forage.

2. MATERIAL AND METHODS

2.1 Nature and Source of Data

The data collection was completed based on area, production, and yield of important millet crops such as sorghum and small millet. It has been collected, for 57 years from 1966-67 to 2022, For pearl millet and finger millet the data has been collected from the website of IIMR (Indian Institute of Millets Research, Hyderabad, Telangana, India). as per: https://www.milletstats.com/apy-stats/.

2.2 Study Period and Crop Selected.

The study pertains to data from a 57 years dataset for pearl millet, and finger millet from 1966-67 to 2022. Pearl Millet and Finger Millet are the important millet crops to selected for the present study.

2.3 Software Used

In the present study, statistical analysis was conducted using the powerful software "R: The Project for Statistical Computing." This software is currently utilized at various universities in statistical departments and across many other applied scientific fields. R is an environment and language for graphics and statistical computing developed by Ross Ihaka and Robert Gentleman, a GNU project similar to the S language developed by John Chambers and colleagues at Bell Laboratories (formerly AT&T, now Lucent Technologies). R is available as free software under the terms of the Free Software Foundation's GNU General Public License in source code form and Mx-Excel.

2.4 Statistical Tools

2.4.1 Fitting of Mathematical Models to the Data

1. **Linear Model,**

$$Y_i = b_0 + b_i t_i \ldots (1)$$

Where Y and t_i are yield and period respectively, b_0 and b_i are constants to be estimated.

2. Quadratic Model,

$$Y_i = b_0 + b_1 t_i + b_2 t^2 \ldots (2)$$

Where Y and t_i's yield and period respectively, b_0 and b_i are constants to be estimated. The quadratic model can be used to model a series that "takes off" or a series that dampens.

3. Cubic Model,

$$Y_i = b_0 + b_1 t_i + b_2 t_i^2 + b_3 t_i^3 \ldots (3)$$

Where Y and t_i are yield and period respectively, b_0 and b_i's constants to be estimated.

4. Exponential Model,

$$Y = b_0 * e^{(b_1 * t)} \ldots (4)$$

Where Y and t_i are yield and time respectively, b_0 and b_i's constants to be estimated, In is Natural log and e is the exponential function.

5. LogarithmicModel,

$$Y_i = b_0 + b_1 In(t)_i \ldots (5)$$

Where Y and t_i are yield and period respectively, b_0 and b_i's constants to be estimated and In is a Natural log.

2.4.2 Computation of Various Statistical Coefficients and Measures

1. Coefficient of Determination

The coefficient of determination is denoted byR^2, and is given by:

$R^2 = 1 - \frac{\sum(Y-\hat{Y})^2}{\sum(Y-\bar{Y})^2}$, ...(6)

where $\bar{Y}$ is the mean value of the variable Y, and $\hat{Y}$ is the trend value of the variable Y obtained by fitting a statistical model (such as a linear model or exponential model as the case may be) to$Y$. Also, the value of the coefficient of determination (R^2) lies between 0 and 1. If the value of R^2 is close to 1, then we conclude that the given model fits the variable Y

2. Root Mean Square Error

The Root mean square error can be simply defined as the square root of the mean square error.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_t)^2} \ldots (7)$$

3. Mean Absolute Percentage Error

The mean absolute error can be easily defined as the arithmetic average of the absolute difference between the actual y_i and predicted values $\hat{y}_t$.

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_t}{y_i}\right| \ldots (8)$$

3. RESULTS AND DISCUSSION

Table 1. Trend Value of Different Regression Models for the Pearl Millet Area (Mha)

Year	Pearl Millet (Actual Value)	Linear	Quadratic	Cubic	Exponential	logarithmic
1966	12.24	12.67	12.50	12.67	12.97	14.90
1967	12.81	12.58	12.42	12.56	12.84	13.80
1968	12.05	12.48	12.34	12.45	12.71	13.15
1969	12.49	12.38	12.26	12.34	12.58	12.69
1970	12.91	12.29	12.19	12.23	12.46	12.34
1971	11.77	12.19	12.11	12.12	12.34	12.05
1972	11.82	12.09	12.02	12.02	12.21	11.80
1973	13.93	12.00	11.94	11.92	12.09	11.59
1974	11.29	11.90	11.86	11.82	11.97	11.40
1975	11.57	11.81	11.78	11.73	11.85	11.23
1976	10.75	11.71	11.70	11.63	11.73	11.08
1977	11.10	11.61	11.61	11.54	11.62	10.94
1978	11.39	11.52	11.53	11.45	11.50	10.81
1979	10.58	11.42	11.44	11.36	11.39	10.70
1980	11.66	11.32	11.36	11.27	11.27	10.59

1981	11.78	11.23	11.27	11.18	11.16	10.48
1982	10.94	11.13	11.19	11.10	11.05	10.39
1983	11.83	11.03	11.10	11.01	10.94	10.30
1984	10.62	10.94	11.01	10.93	10.83	10.21
1985	10.65	10.84	10.92	10.84	10.72	10.13
1986	11.27	10.74	10.83	10.76	10.62	10.05
1987	8.71	10.65	10.74	10.68	10.51	9.98
1988	12.04	10.55	10.65	10.59	10.41	9.91
1989	10.90	10.45	10.56	10.51	10.30	9.84
1990	10.48	10.36	10.47	10.43	10.20	9.77
1991	10.03	10.26	10.38	10.35	10.10	9.71
1992	10.62	10.16	10.29	10.27	10.00	9.65
1993	9.55	10.07	10.19	10.18	9.90	9.59
1994	10.22	9.97	10.10	10.10	9.80	9.54
1995	9.32	9.87	10.01	10.02	9.70	9.48
1996	9.98	9.78	9.91	9.94	9.61	9.43
1997	9.89	9.68	9.81	9.85	9.51	9.38
1998	9.30	9.58	9.72	9.77	9.42	9.33
1999	8.90	9.49	9.62	9.68	9.32	9.28
2000	9.83	9.39	9.52	9.59	9.23	9.24
2001	9.53	9.29	9.43	9.50	9.14	9.19
2002	7.74	9.20	9.33	9.41	9.05	9.15
2003	10.61	9.10	9.23	9.32	8.96	9.11
2004	9.23	9.00	9.13	9.23	8.87	9.06
2005	9.58	8.91	9.03	9.14	8.78	9.02
2006	9.51	8.81	8.93	9.04	8.69	8.98
2007	9.57	8.71	8.83	8.94	8.61	8.95
2008	8.75	8.62	8.72	8.84	8.52	8.91
2009	8.90	8.52	8.62	8.74	8.44	8.87
2010	9.61	8.42	8.52	8.63	8.35	8.84
2011	8.78	8.33	8.41	8.53	8.27	8.80
2012	7.30	8.23	8.31	8.42	8.19	8.77
2013	7.81	8.13	8.20	8.30	8.10	8.73
2014	7.32	8.04	8.10	8.19	8.02	8.70
2015	7.13	7.94	7.99	8.07	7.94	8.67
2016	7.46	7.84	7.88	7.95	7.87	8.64
2017	7.48	7.75	7.78	7.83	7.79	8.61
2018	7.11	7.65	7.67	7.70	7.71	8.58
2019	7.54	7.55	7.56	7.57	7.63	8.55
2020	7.65	7.46	7.45	7.43	7.56	8.52
2021	6.84	7.36	7.34	7.30	7.48	8.49
2022	7.57	7.26	7.23	7.15	7.41	8.46

Table 1 describes the trend of pearl millet, commonly known as Bajra, so this table describes the trend of the area of Bajra. The unit of area has been taken in (million hectares). The trend of the pearl millet area shows the cubic and quadratic models showing some similarities, after getting the result of the validation parameters some justify the cubic model was the best fit for all these models[3], and the value of the coefficient of determination for the quadratic model was (0.84) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was, 0.71 and 5.91 respectively but in case of cubic model the value of the coefficient of determination for the quadratic model was (0.86) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was, 0.69 and 5.51 respectively after getting this result we can say quadratic model shows the second best model after cubic model, so cubic trend was showed best result for the validation of actual values of pearl millet area.

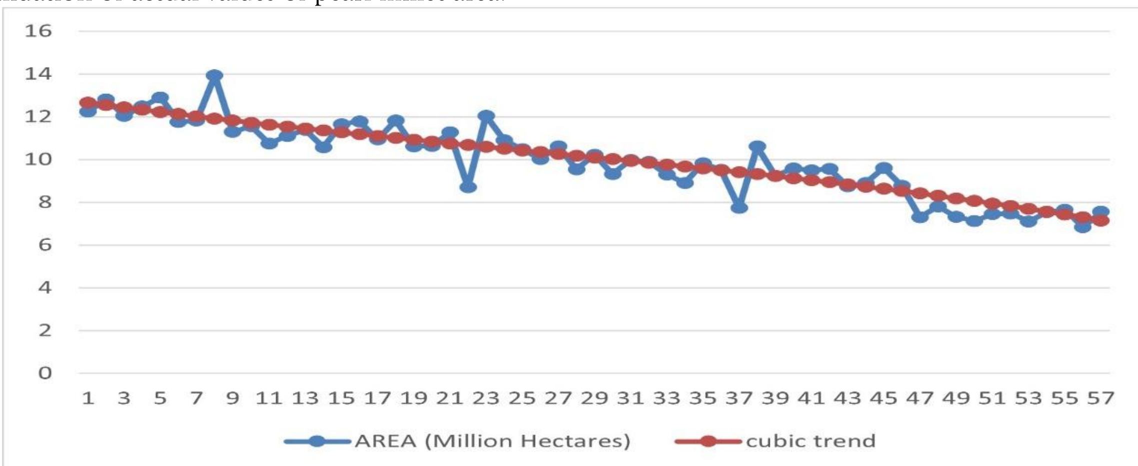

Figure 1. Graphical representation of the Actual value and cubic trend value for Pearl millet area

Fig. 1 shows the graphical presentation of the pearl millet area. Figure 1 intends to show the trend for the area of pearl millet; the unit of area is taken to be million hectares, and we have seen the trend of pearl millet showing a continuously decreasing trend. For the validation of this data, we have selected some statistical parameters, viz., coefficient of determination, root mean square error, and mean absolute percentage error. The value of the coefficient of determination shows the accuracy of the model's efficiency [3]. According to these values, we determined that the cubic regression model provided the best fit for pearl millet, as the value of the cubic trend was closest to the actual value of pearl millet and showed the best validation for this data. After obtaining these results, we have declared the area of pearl millet to be showing a continuously decreasing trend.

Table 2. Trend Value of Different Regression Models for the Pearl Millet Production (MT)

Year	Pearl Millet (Actual Value)	Linear	Quadratic	Cubic	Exponential	logarithmic
1966	4.47	4.28	4.98	5.32	4.39	2.18
1967	5.19	4.38	4.99	5.26	4.46	3.27
1968	3.8	4.48	5.01	5.21	4.52	3.91
1969	5.33	4.58	5.03	5.18	4.59	4.36
1970	8.03	4.69	5.06	5.15	4.66	4.71
1971	5.32	4.79	5.09	5.13	4.73	5.00
1972	3.93	4.89	5.12	5.12	4.80	5.24
1973	7.52	4.99	5.15	5.11	4.88	5.45
1974	3.27	5.09	5.19	5.12	4.95	5.64
1975	5.74	5.19	5.23	5.14	5.03	5.80
1976	5.85	5.29	5.28	5.16	5.10	5.95
1977	4.73	5.39	5.32	5.19	5.18	6.09
1978	5.57	5.49	5.37	5.23	5.26	6.21
1979	3.95	5.59	5.43	5.27	5.34	6.33
1980	5.34	5.69	5.49	5.32	5.42	6.44
1981	5.54	5.79	5.55	5.38	5.50	6.54

1982	5.13	5.89	5.61	5.45	5.58	6.64
1983	7.72	5.99	5.68	5.52	5.67	6.73
1984	6.05	6.09	5.75	5.60	5.75	6.81
1985	3.66	6.19	5.82	5.68	5.84	6.89
1986	4.51	6.29	5.89	5.77	5.93	6.97
1987	3.3	6.39	5.97	5.87	6.02	7.04
1988	7.78	6.49	6.06	5.97	6.11	7.11
1989	6.65	6.59	6.14	6.07	6.20	7.18
1990	6.89	6.69	6.23	6.18	6.29	7.24
1991	4.67	6.80	6.32	6.29	6.39	7.31
1992	8.88	6.90	6.42	6.41	6.48	7.37
1993	4.97	7.00	6.52	6.53	6.58	7.42
1994	7.16	7.10	6.62	6.66	6.68	7.48
1995	5.38	7.20	6.73	6.79	6.78	7.53
1996	7.87	7.30	6.83	6.92	6.89	7.58
1997	7.64	7.40	6.95	7.06	6.99	7.63
1998	6.96	7.50	7.06	7.19	7.10	7.68
1999	5.78	7.60	7.18	7.33	7.20	7.73
2000	6.76	7.70	7.30	7.48	7.31	7.77
2001	8.28	7.80	7.42	7.62	7.42	7.82
2002	4.72	7.90	7.55	7.77	7.53	7.86
2003	12.11	8.00	7.68	7.92	7.65	7.90
2004	7.93	8.10	7.82	8.07	7.76	7.94
2005	7.68	8.20	7.95	8.22	7.88	7.98
2006	8.42	8.30	8.09	8.37	8.00	8.02
2007	9.97	8.40	8.24	8.52	8.12	8.06
2008	8.89	8.50	8.38	8.67	8.24	8.10
2009	6.51	8.60	8.53	8.82	8.37	8.13
2010	10.37	8.71	8.69	8.97	8.49	8.17
2011	10.28	8.81	8.84	9.13	8.62	8.20
2012	8.74	8.91	9.00	9.28	8.75	8.24
2013	9.25	9.01	9.16	9.43	8.89	8.27
2014	9.18	9.11	9.33	9.58	9.02	8.30
2015	8.07	9.21	9.50	9.72	9.16	8.34
2016	9.73	9.31	9.67	9.87	9.29	8.37
2017	9.21	9.41	9.85	10.01	9.44	8.40
2018	8.66	9.51	10.03	10.15	9.58	8.43
2019	10.36	9.61	10.21	10.29	9.72	8.46
2020	10.86	9.71	10.39	10.43	9.87	8.49
2021	9.78	9.81	10.58	10.57	10.02	8.51
2022	11.43	9.91	10.77	10.70	10.17	8.54

Table 2 indicates the different trend values for pearl millet production; the unit of production for pearl millet is taken in million tonnes. For this analysis, we have used five different statistical regression models to find the best model for showing the trend. After analyzing all the various regression models, we concluded that the cubic trend model was showing the best result. The trend of the pearl millet production shows the cubic and quadratic models showing some similarities, after getting the result of the validation parameters some justify the cubic model was the best fit for all these models, and the value of the coefficient of determination for the quadratic model was (0.61) and error viz., root mean square error (RMSE)[4] and mean absolute percentage error (MAPE) was, 1.39 and 17.35 respectively but in case of cubic model the value of the coefficient of determination for the quadratic model was (0.60) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was, 1.38 and 17. 32 respectively. After getting this result, we can say the quadratic model shows the second-best model after the cubic model, so the cubic trend showed the best result for the validation of actual values of pearl millet production.

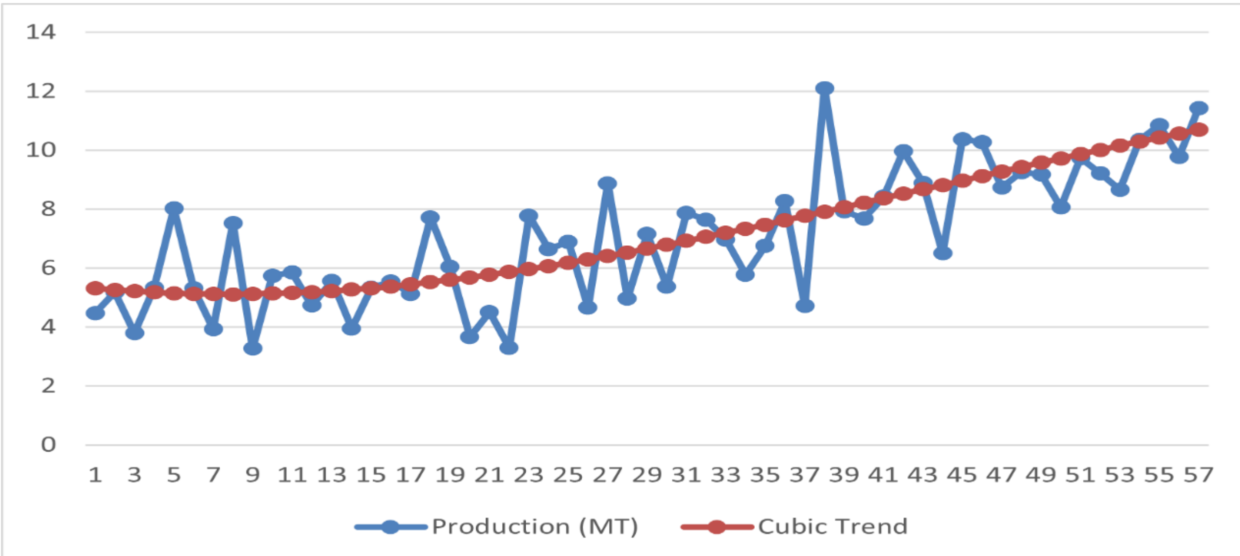

Figure 2. Graphical representation of the Actual value and the cubic trend value for Pearl millet Production

Fig. 2 shows the graphical presentation of pearl millet production. Fig.2 intends to show the trend for the production of pearl millet in the unit of production taken in million tonnes, and we have seen the trend of pearl millet showing a continuously increasing trend. For the validation of this data, we have selected some statistical parameters, viz., coefficient of determination, root mean square error, and mean absolute percentage error. The value of the coefficient of determination shows the accuracy of the model's efficiency. According to these values, we decided the cubic regression model was showing the best fit for pearl millet production. The value of the cubic trend was closest to the actual value of pearl millet and shows the best validation for this data. After getting these results, we have declared the production of pearl millet, showing a continuously increasing trend.

Table 3. Trend Value of Different Regression Models for the Pearl Millet Productivity (T/ha)

Year	Pearl Millet Productivity (Actual Value)	Linear	Quadratic	Cubic	Exponential	logarithmic
1966	0.37	0.23	0.43	0.42	0.34	-0.11
1967	0.41	0.25	0.43	0.42	0.35	0.08
1968	0.32	0.27	0.42	0.42	0.36	0.20
1969	0.43	0.29	0.42	0.42	0.36	0.28
1970	0.62	0.30	0.42	0.42	0.37	0.34
1971	0.45	0.32	0.42	0.42	0.38	0.39
1972	0.33	0.34	0.42	0.43	0.39	0.43
1973	0.54	0.36	0.43	0.43	0.40	0.47
1974	0.29	0.38	0.43	0.43	0.41	0.50
1975	0.50	0.40	0.43	0.44	0.42	0.53

1976	0.54	0.42	0.44	0.44	0.43	0.56
1977	0.43	0.44	0.44	0.45	0.45	0.58
1978	0.49	0.45	0.45	0.46	0.46	0.61
1979	0.37	0.47	0.46	0.47	0.47	0.63
1980	0.46	0.49	0.47	0.47	0.48	0.65
1981	0.47	0.51	0.47	0.48	0.49	0.66
1982	0.47	0.53	0.48	0.49	0.51	0.68
1983	0.65	0.55	0.49	0.50	0.52	0.70
1984	0.57	0.57	0.51	0.51	0.53	0.71
1985	0.34	0.59	0.52	0.53	0.54	0.73
1986	0.40	0.60	0.53	0.54	0.56	0.74
1987	0.38	0.62	0.54	0.55	0.57	0.75
1988	0.65	0.64	0.56	0.57	0.59	0.76
1989	0.61	0.66	0.57	0.58	0.60	0.78
1990	0.66	0.68	0.59	0.60	0.62	0.79
1991	0.47	0.70	0.61	0.61	0.63	0.80
1992	0.84	0.72	0.62	0.63	0.65	0.81
1993	0.52	0.73	0.64	0.65	0.66	0.82
1994	0.70	0.75	0.66	0.67	0.68	0.83
1995	0.58	0.77	0.68	0.69	0.70	0.84
1996	0.79	0.79	0.70	0.71	0.72	0.85
1997	0.77	0.81	0.72	0.73	0.73	0.86
1998	0.75	0.83	0.74	0.75	0.75	0.87
1999	0.65	0.85	0.77	0.77	0.77	0.87
2000	0.69	0.87	0.79	0.80	0.79	0.88
2001	0.87	0.88	0.82	0.82	0.81	0.89
2002	0.61	0.90	0.84	0.84	0.83	0.90
2003	1.14	0.92	0.87	0.87	0.85	0.91
2004	0.86	0.94	0.90	0.90	0.88	0.91
2005	0.80	0.96	0.92	0.92	0.90	0.92
2006	0.89	0.98	0.95	0.95	0.92	0.93
2007	1.04	1.00	0.98	0.98	0.94	0.93
2008	1.02	1.02	1.01	1.01	0.97	0.94
2009	0.73	1.03	1.04	1.04	0.99	0.95
2010	1.08	1.05	1.07	1.08	1.02	0.95
2011	1.17	1.07	1.11	1.11	1.04	0.96
2012	1.20	1.09	1.14	1.14	1.07	0.96
2013	1.18	1.11	1.18	1.18	1.10	0.97
2014	1.25	1.13	1.21	1.21	1.12	0.98
2015	1.13	1.15	1.25	1.25	1.15	0.98
2016	1.30	1.16	1.28	1.28	1.18	0.99
2017	1.23	1.18	1.32	1.32	1.21	0.99
2018	1.22	1.20	1.36	1.36	1.24	1.00
2019	1.37	1.22	1.40	1.40	1.27	1.00
2020	1.42	1.24	1.44	1.44	1.31	1.01
2021	1.43	1.26	1.48	1.48	1.34	1.01
2022	1.51	1.28	1.52	1.53	1.37	1.02

Table 3. describes the trend of pearl millet, commonly known as Bajra, so this table describes the trend of the productivity of pearl millet. The unit of pearl millet productivity has been taken in (tonnes per hectare). The trend of the pearl millet productivity shows that the cubic and quadratic models show some similarities. After getting the result of the validation parameters, some justified the cubic model was the best fit for all these models, and the value of the coefficient of determination for the quadratic model was (0.88) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was 0.11 and 15.04, respectively, but in the case of the cubic model, the value of the coefficient of determination for the quadratic model was (0.90) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was 0.10 and 14.25, respectively. After getting this result, we can say the quadratic model shows the second-best model after the cubic model, so the cubic trend showed the best result for the validation of actual values of pearl millet productivity.

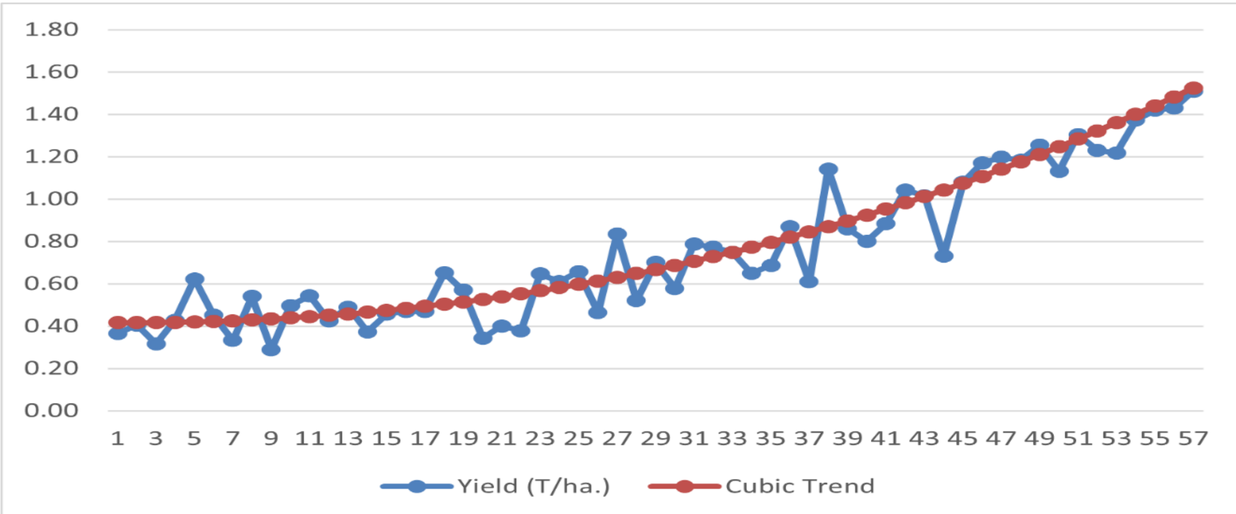

Figure 3. Graphical representation of the Actual value and the cubic trend value for Pearl millet Productivity

Figure 3 shows the graphical presentation of pearl millet productivity. Fig. 3 intends to show the trend for the production of pearl millet in the unit of productivity taken in tonnes per hectare, and we have seen the trend of pearl millet showing a continuously increasing trend. For the validation of this data, we have selected some statistical parameters, viz., coefficient of determination, root mean square error, and mean absolute percentage error. [5] The value of the coefficient of determination shows the accuracy of the model's efficiency. According to these values, we decided the cubic regression model was showing the best fit for pearl millet productivity. The value of the cubic trend was closest to the actual value of pearl millet and shows the best validation for this data. After getting these results, we have declared the productivity of pearl millet, showing a continuously increasing trend.

Table 4. Model validation parameters of Pearl Millet Crop

Variable	Model	R^2	RMSE	MAPE
Area	Linear	0.83	0.69	5.64
	Quadratic	0.84	0.71	5.91
	Exponential	0.82	0.69	5.46
	Cubic	0.86	0.69	5.51
	Logarithmic	0.66	0.99	8.38
Production	Linear	0.55	1.44	18.22
	Quadratic	0.61	1.39	17.35

	Exponential	0.61	1.41	17.54
	Cubic	0.60	1.38	17.32
	Logarithmic	0.39	1.73	23.47
Productivity	Linear	0.82	0.14	18.77
	Quadratic	0.90	0.10	14.16
	Exponential	0.88	0.11	15.04
	Cubic	0.90	0.10	14.25
	Logarithmic	0.53	0.23	32.18

Table 4: To determine the most suitable regression models for estimating Area, Production, and Productivity, five functional forms were tested: Linear, Quadratic, Exponential, Cubic, and Logarithmic. Model performance was evaluated using the coefficient of determination (R^2), root mean square error (RMSE), and mean absolute percentage error (MAPE). For Area, the Cubic model achieved the highest R^2 (0.86) and shared the lowest RMSE (0.69), with a relatively low MAPE (5.51), indicating strong explanatory power and predictive accuracy. For Production, the Cubic model again outperformed others, achieving the lowest RMSE (1.38) and MAPE (17.32), suggesting better fit and predictive reliability. For Productivity, the Quadratic model showed the best overall performance, with the highest R^2 (0.90), lowest RMSE (0.10), and lowest MAPE (14.16), signifying excellent model fit and accuracy. Across all variables, Logarithmic models consistently performed the worst, with lower R^2 values and higher error metrics, indicating they are unsuitable for this dataset. Overall, non-linear models, particularly Quadratic and Cubic, provided better fits compared to simple linear models, highlighting the benefit of capturing higher-order relationships in the data. Across all variables, Logarithmic models consistently performed the worst, with lower R^2 values and higher error metrics, indicating they are unsuitable for this dataset. [6] Overall, non-linear models, particularly Quadratic and Cubic, provided better fits compared to simple linear models, highlighting the benefit of capturing higher-order relationships in the data

Table 5. Trend values of different Regression models for Finger Millet Crop Area (Mha)

Year	Finger Millet (Actual Value)	Linear	Quadratic	Cubic	Exponential	logarithmic
1966	1.98	2.73	2.60	2.17	2.92	3.25
1967	2.29	2.70	2.58	2.24	2.87	2.95
1968	2.24	2.67	2.56	2.31	2.82	2.77
1969	2.78	2.64	2.55	2.37	2.77	2.64
1970	2.47	2.61	2.53	2.42	2.73	2.54
1971	2.43	2.58	2.51	2.46	2.68	2.46
1972	2.33	2.55	2.49	2.49	2.63	2.39
1973	2.36	2.52	2.47	2.52	2.59	2.33
1974	2.46	2.49	2.45	2.54	2.55	2.28
1975	2.63	2.46	2.43	2.55	2.50	2.23
1976	2.50	2.43	2.41	2.56	2.46	2.19
1977	2.60	2.40	2.39	2.56	2.42	2.15
1978	2.71	2.37	2.36	2.55	2.38	2.11
1979	2.61	2.34	2.34	2.54	2.34	2.08
1980	2.53	2.31	2.32	2.52	2.30	2.05
1981	2.61	2.28	2.29	2.50	2.26	2.02
1982	2.41	2.25	2.27	2.47	2.22	2.00
1983	2.56	2.21	2.24	2.44	2.19	1.97
1984	2.39	2.18	2.22	2.40	2.15	1.95
1985	2.40	2.15	2.19	2.36	2.11	1.92

1986	2.40	2.12	2.16	2.32	2.08	1.90
1987	2.26	2.09	2.14	2.27	2.04	1.88
1988	2.32	2.06	2.11	2.22	2.01	1.86
1989	2.34	2.03	2.08	2.17	1.97	1.84
1990	2.17	2.00	2.05	2.11	1.94	1.82
1991	2.13	1.97	2.02	2.06	1.91	1.81
1992	1.91	1.94	1.99	2.00	1.88	1.79
1993	1.88	1.91	1.96	1.94	1.84	1.77
1994	1.76	1.88	1.92	1.88	1.81	1.76
1995	1.77	1.85	1.89	1.81	1.78	1.74
1996	1.78	1.82	1.86	1.75	1.75	1.73
1997	1.66	1.79	1.82	1.69	1.72	1.71
1998	1.76	1.76	1.79	1.62	1.69	1.70
1999	1.63	1.73	1.75	1.56	1.66	1.69
2000	1.76	1.70	1.72	1.50	1.64	1.67
2001	1.65	1.67	1.68	1.44	1.61	1.66
2002	1.42	1.64	1.64	1.38	1.58	1.65
2003	1.67	1.61	1.61	1.32	1.56	1.64
2004	1.55	1.58	1.57	1.26	1.53	1.63
2005	1.53	1.55	1.53	1.20	1.50	1.62
2006	1.18	1.52	1.49	1.15	1.48	1.60
2007	1.39	1.49	1.45	1.10	1.45	1.59
2008	1.38	1.45	1.41	1.06	1.43	1.58
2009	1.27	1.42	1.37	1.01	1.40	1.57
2010	1.29	1.39	1.33	0.97	1.38	1.56
2011	1.18	1.36	1.29	0.94	1.36	1.55
2012	1.13	1.33	1.24	0.90	1.33	1.54
2013	1.19	1.30	1.20	0.88	1.31	1.53
2014	1.21	1.27	1.16	0.85	1.29	1.53
2015	1.14	1.24	1.11	0.84	1.27	1.52
2016	1.02	1.21	1.07	0.82	1.25	1.51
2017	1.19	1.18	1.02	0.82	1.23	1.50
2018	0.89	1.15	0.97	0.82	1.21	1.49
2019	1.00	1.12	0.93	0.82	1.18	1.48
2020	1.16	1.09	0.88	0.83	1.16	1.47
2021	1.21	1.06	0.83	0.85	1.15	1.47
2022	1.73	1.03	0.78	0.88	1.13	1.46

Table 5 describes the trend of finger millet, commonly known as Ragi. This table describes the trend of the Area of finger millet. The unit of finger millet area has been taken in (Million per hectare). The trend of the finger millet area shows that the cubic and quadratic models show some similarities. After getting the result of the validation parameters, some justified the cubic model was the best fit for all these models, and the value of the coefficient of determination for the quadratic model was (0.88) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was 0.11 and 15.04, respectively, but in the case of the cubic model, the value of the coefficient of determination for the quadratic model was (0.90) and error viz., root mean square error (RMSE) and mean absolute percentage error (MAPE) was 0.10 and 14.25, respectively. After getting this result, we can say the [6] quadratic model shows the second-best model after the cubic model, so the cubic trend showed the best result for the validation of the actual values of finger millet area

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Figure 4. Graphical representation of the Actual value and the cubic trend value for Finger millet Area

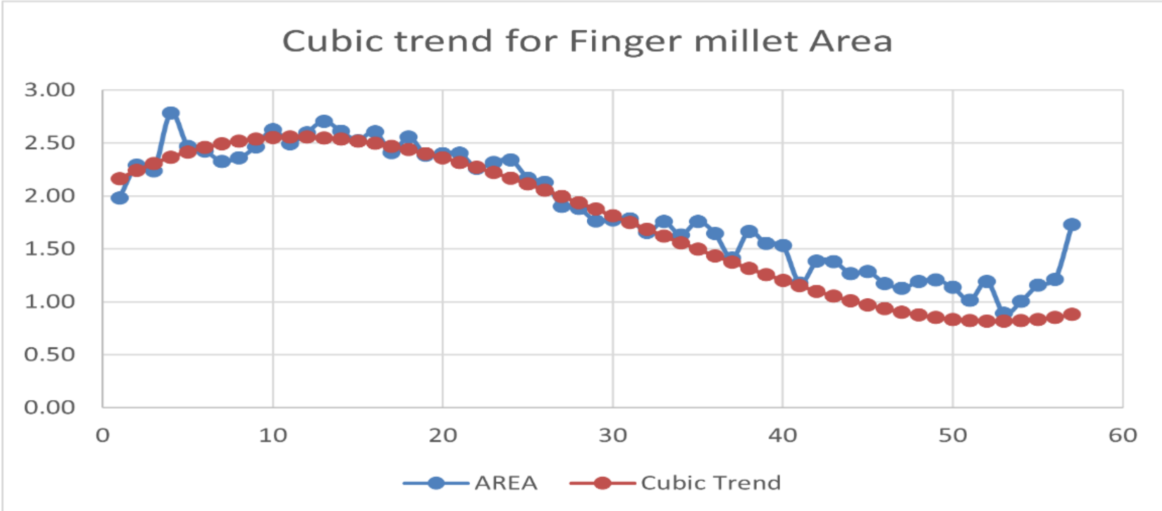


Figure 4. The graph uses a fitted cubic trend line to show how the area under finger millet cultivation has changed over time. The smooth red line shows the cubic trend, and the blue line with markers shows the actual area data (area). Early on, the graph indicates a general increase in area, which peaks at about the tenth time unit. The area then gradually decreases until about the 50th unit, after which it slightly increases toward the finish. This non-linear pattern with a single peak and trough is captured by the cubic trend, suggesting that it is appropriate for simulating such variations. Even if there are some notable fluctuations in the real data, the overall pattern is smoothed down by the cubic trend. In addition to supporting additional analysis for planning and forecasting in agricultural research, this visualization aids in comprehending the long-term changes in finger millet area.

Table 6. Trend values of different Regression models for Finger Millet Production (Mt.)

Year	Finger Millet (Actual Value)	Linear	Quadratic	Cubic	Exponential	logarithmic
1966	1.63	2.64	1.83	1.80	3.00	2.59
1967	1.88	2.63	1.90	1.87	2.96	2.48
1968	1.65	2.61	1.97	1.95	2.91	2.42
1969	2.12	2.59	2.03	2.01	2.86	2.38
1970	2.16	2.57	2.09	2.08	2.82	2.34
1971	2.21	2.55	2.14	2.14	2.77	2.31
1972	1.92	2.53	2.19	2.20	2.73	2.29
1973	2.07	2.51	2.24	2.25	2.69	2.27
1974	2.14	2.49	2.29	2.30	2.64	2.25
1975	2.80	2.47	2.33	2.34	2.60	2.23
1976	2.04	2.45	2.37	2.39	2.56	2.22
1977	2.87	2.44	2.40	2.43	2.52	2.21
1978	3.20	2.42	2.44	2.46	2.48	2.19
1979	2.72	2.40	2.47	2.49	2.44	2.18
1980	2.42	2.38	2.49	2.52	2.40	2.17
1981	2.96	2.36	2.52	2.55	2.36	2.16
1982	2.22	2.34	2.54	2.57	2.33	2.15
1983	2.83	2.32	2.55	2.59	2.29	2.14
1984	2.53	2.30	2.57	2.60	2.25	2.14
1985	2.52	2.28	2.58	2.61	2.22	2.13

1986	2.71	2.26	2.58	2.62	2.18	2.12
1987	2.32	2.25	2.59	2.63	2.15	2.11
1988	2.41	2.23	2.59	2.63	2.11	2.11
1989	2.77	2.21	2.59	2.62	2.08	2.10
1990	2.34	2.19	2.58	2.62	2.05	2.09
1991	2.58	2.17	2.57	2.61	2.01	2.09
1992	2.53	2.15	2.56	2.60	1.98	2.08
1993	2.60	2.13	2.55	2.59	1.95	2.08
1994	2.34	2.11	2.53	2.57	1.92	2.07
1995	2.50	2.09	2.51	2.55	1.89	2.07
1996	2.34	2.07	2.48	2.52	1.86	2.06
1997	2.09	2.06	2.45	2.50	1.83	2.06
1998	2.61	2.04	2.42	2.47	1.80	2.05
1999	2.29	2.02	2.39	2.43	1.77	2.05
2000	2.73	2.00	2.35	2.40	1.74	2.04
2001	2.37	1.98	2.31	2.36	1.72	2.04
2002	1.32	1.96	2.26	2.32	1.69	2.03
2003	1.97	1.94	2.22	2.27	1.66	2.03
2004	2.43	1.92	2.17	2.23	1.64	2.02
2005	2.35	1.90	2.11	2.18	1.61	2.02
2006	1.44	1.88	2.06	2.12	1.58	2.02
2007	2.15	1.87	2.00	2.07	1.56	2.01
2008	2.04	1.85	1.93	2.01	1.53	2.01
2009	1.89	1.83	1.87	1.95	1.51	2.01
2010	2.19	1.81	1.80	1.88	1.49	2.00
2011	1.93	1.79	1.72	1.82	1.46	2.00
2012	1.57	1.77	1.65	1.75	1.44	2.00
2013	1.98	1.75	1.57	1.67	1.42	1.99
2014	2.06	1.73	1.49	1.60	1.39	1.99
2015	1.82	1.71	1.40	1.52	1.37	1.99
2016	1.39	1.69	1.31	1.44	1.35	1.98
2017	1.99	1.68	1.22	1.36	1.33	1.98
2018	0.89	1.66	1.13	1.27	1.31	1.98
2019	0.10	1.64	1.03	1.18	1.29	1.97
2020	1.15	1.62	0.93	1.09	1.27	1.97
2021	1.21	1.60	0.82	1.00	1.25	1.97
2022	0.19	1.58	0.71	0.90	1.23	1.97

Table 6. A comparison of the actual Finger Millet output from 1966 to 2022 with the values forecasted by five distinct trend models, linear, quadratic, cubic, exponential, and logarithmic, is shown in this table. With large peaks in the late 1970s, mid-1980s, and late 1990s, as well as a rapid fall after 2000, the actual production levels show considerable variety over time. The non-linear nature of real production patterns is not captured by the linear model, which displays a steady fall. Although it still misses mid-term oscillations, the quadratic model performs marginally better, showing an initial increase followed by a slow drop. The most realistic depiction is provided by the cubic model, which successfully captures production trends peaks and valleys as well as turning points. Because of this, it may be used to model non-linear agricultural production data from the actual world. On the other hand, the exponential model is less accurate since it overestimates productivity in the early years and underestimates it in the latter decades. Similarly, none of the production peaks or

troughs are represented by the logarithmic model, which flattens out early. All things considered, the cubic model fits the data the best, hence facilitating its application in Finger Millet production forecasts and policy planning.

Figure 5. Graphical representation of the Actual value and the cubic trend value for Finger millet Production

Fig. 5 By contrasting real production values (blue line) with a fitted cubic trend (red line), the graph shows the trajectory of finger millet production throughout time. Production first increases steadily before gradually declining after reaching a high around the 20th to 25th data point. These increases and falls are well captured by the cubic trend line, which points to a non-linear pattern in long-term production. Actual value fluctuations reflect outside factors like changes in the climate or in legislation. Because it accurately depicts both development and decline phases, the cubic model fits the data well and can be used to predict future production trends or policy assessments.

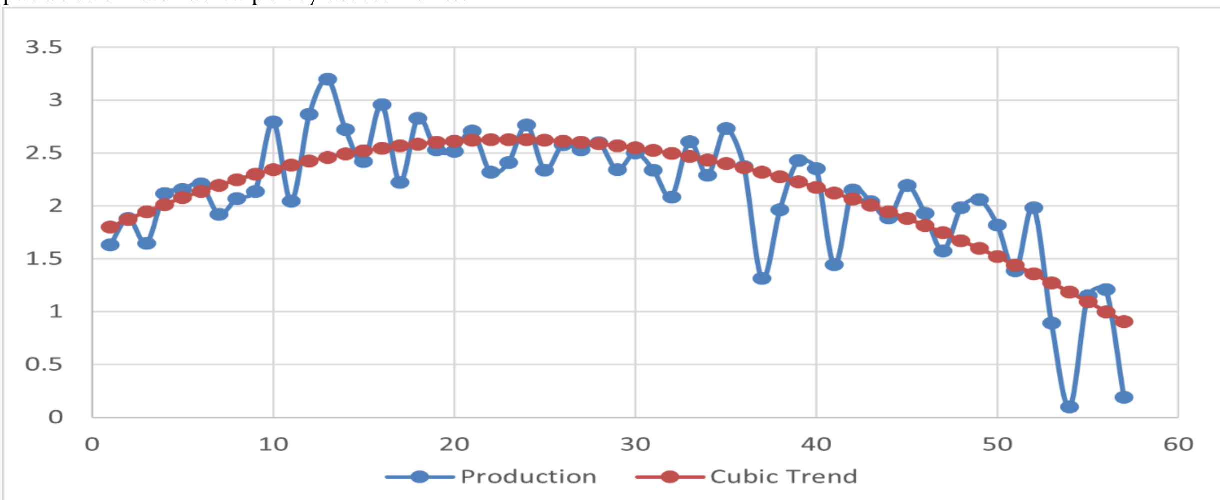


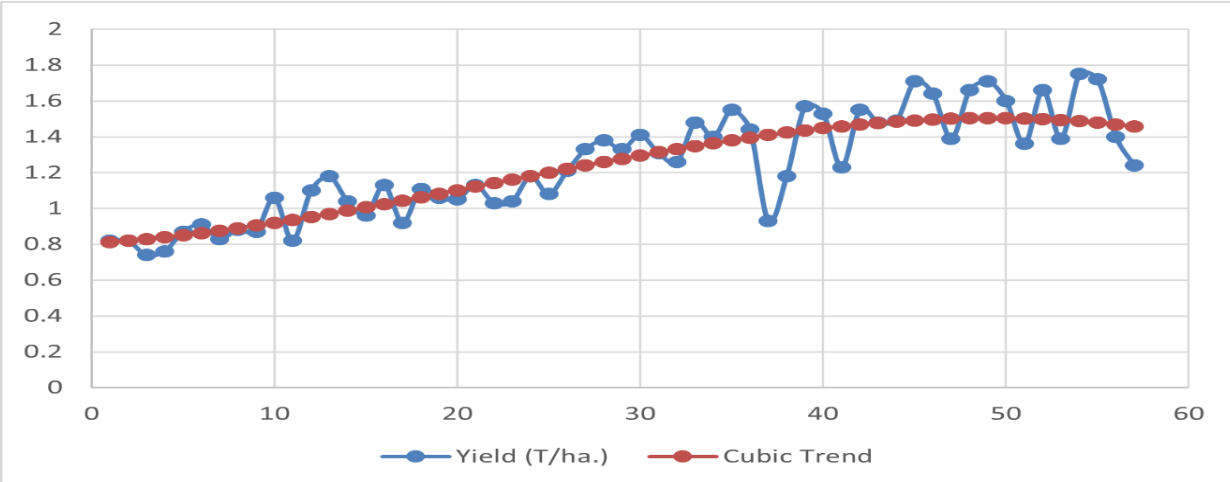
Table 7. Trend values of different Regression models for Finger Millet Productivity (T/ha)

Year	Finger Millet (Actual Value)	Linear	Quadratic	Cubic	Exponential	logarithmic
1966	0.82	0.82	0.74	0.81	0.85	0.43
1967	0.82	0.83	0.76	0.82	0.86	0.61
1968	0.74	0.85	0.79	0.83	0.87	0.72
1969	0.76	0.86	0.81	0.84	0.88	0.79
1970	0.87	0.88	0.83	0.85	0.89	0.85
1971	0.91	0.89	0.85	0.86	0.90	0.90
1972	0.83	0.91	0.87	0.88	0.91	0.94
1973	0.88	0.92	0.90	0.89	0.93	0.97
1974	0.87	0.94	0.92	0.90	0.94	1.01
1975	1.06	0.95	0.94	0.92	0.95	1.03
1976	0.82	0.97	0.96	0.94	0.96	1.06
1977	1.1	0.98	0.98	0.95	0.97	1.08
1978	1.18	1.00	1.00	0.97	0.99	1.10
1979	1.04	1.01	1.01	0.99	1.00	1.12
1980	0.96	1.03	1.03	1.01	1.01	1.14
1981	1.13	1.04	1.05	1.02	1.02	1.16
1982	0.92	1.06	1.07	1.04	1.04	1.17
1983	1.11	1.07	1.09	1.06	1.05	1.19

1984	1.06	1.09	1.10	1.08	1.06	1.20
1985	1.05	1.10	1.12	1.10	1.08	1.21
1986	1.13	1.12	1.13	1.12	1.09	1.23
1987	1.03	1.13	1.15	1.14	1.10	1.24
1988	1.04	1.15	1.17	1.16	1.12	1.25
1989	1.18	1.16	1.18	1.18	1.13	1.26
1990	1.08	1.18	1.19	1.20	1.15	1.27
1991	1.21	1.19	1.21	1.22	1.16	1.28
1992	1.33	1.21	1.22	1.24	1.18	1.29
1993	1.38	1.22	1.24	1.26	1.19	1.30
1994	1.33	1.24	1.25	1.28	1.21	1.31
1995	1.41	1.25	1.26	1.30	1.22	1.32
1996	1.31	1.27	1.27	1.31	1.24	1.33
1997	1.26	1.28	1.28	1.33	1.25	1.34
1998	1.48	1.30	1.30	1.35	1.27	1.35
1999	1.40	1.31	1.31	1.36	1.28	1.35
2000	1.55	1.33	1.32	1.38	1.30	1.36
2001	1.44	1.34	1.33	1.40	1.32	1.37
2002	0.93	1.36	1.34	1.41	1.33	1.38
2003	1.18	1.37	1.35	1.42	1.35	1.38
2004	1.57	1.39	1.35	1.44	1.37	1.39
2005	1.53	1.40	1.36	1.45	1.39	1.40
2006	1.23	1.42	1.37	1.46	1.40	1.40
2007	1.55	1.43	1.38	1.47	1.42	1.41
2008	1.48	1.45	1.39	1.48	1.44	1.41
2009	1.49	1.46	1.39	1.48	1.46	1.42
2010	1.71	1.48	1.40	1.49	1.48	1.43
2011	1.64	1.49	1.40	1.50	1.49	1.43
2012	1.39	1.51	1.41	1.50	1.51	1.44
2013	1.66	1.52	1.42	1.50	1.53	1.44
2014	1.71	1.54	1.42	1.50	1.55	1.45
2015	1.6	1.55	1.42	1.50	1.57	1.45
2016	1.36	1.57	1.43	1.50	1.59	1.46
2017	1.66	1.58	1.43	1.50	1.61	1.46
2018	1.39	1.60	1.44	1.49	1.63	1.47
2019	1.75	1.61	1.44	1.49	1.65	1.47
2020	1.72	1.63	1.44	1.48	1.67	1.48
2021	1.4	1.64	1.44	1.47	1.69	1.48
2022	1.24	1.66	1.44	1.46	1.72	1.49

Table 7. The dataset includes trend values forecasted by six distinct models: linear, quadratic, cubic, exponential, and logarithmic. It also shows the actual productivity of finger millet in India from 1966 to 2022. Up until the early 1980s, actual productivity was low, averaging less than 1.0 tonnes/hectare. After that, there is a steady increase that peaks between 2010 and 2015, when values were close to 1.7 tonnes/hectare. There has been a minor decrease in recent years. The model that most accurately depicts the non-linear evolution of finger millet yields over time is the cubic trend, which closely reflects the increase and a final little drop in productivity. The current standstill and decline in output are not reflected in the linear and exponential models, which repeatedly overestimate production in subsequent years. Throughout the era, and particularly

in the early and middle phases, the logarithmic model understates values. Although it performs rather well, the quadratic model is not as good as the cubic model in reflecting data inflection points. Despite some



swings, this data shows that finger millet productivity has increased overall over the past 50 years. Because of its precision, the cubic model is especially helpful for long-term trend monitoring and forecasting, which supports its application in sustainability evaluations and agricultural policy planning.

Figure 6. Graphical representation of the Actual value and the cubic trend value for Finger millet Productivity

Fig.6 With a cubic trend line in red and actual yield values represented by a blue line, the graph shows the yield trend of finger millet (in tons per hectare) over a period of 57 years. From the late 1960s to the mid-2010s, the yield showed a general rising trend, peaking at about 1.7 t/ha. In recent years, however, there has been a modest fall. This non-linear history, which includes both periods of tremendous expansion and modest fall, is well captured by the cubic trend line. This implies that a cubic model offers a good match for predicting yield over the long run and assessing productivity changes in the production of finger millet.

Table 8. Model Validation Parameters for Finger Millet Crop

Variable	Model	R^2	RMSE	MAPE
Area	Linear	0.82	0.23	9.90
	Quadratic	0.83	0.22	9.09
	Exponential	0.77	0.26	10.59
	Cubic	0.94	0.22	10.91
	Logarithmic	0.51	0.38	18.16
Production	Linear	0.26	0.51	58.52
	Quadratic	0.67	0.34	11.25
	Exponential	0.19	0.61	12.12
	Cubic	0.67	0.34	9.67
	Logarithmic	0.50	0.58	17.25
Productivity	Linear	0.74	0.14	9.28
	Quadratic	0.76	0.10	9.57
	Exponential	0.71	0.11	9.81
	Cubic	0.77	0.10	8.50
	Logarithmic	0.66	0.23	11.52

Table 8 describes five distinct regression models Linear, Quadratic, Exponential, Cubic, and Logarithmic applied to three important variables—Area, Production, and Productivity of Finger Millet are compares them in this table. Three statistical measures are used to evaluate the models: MAPE (Mean Absolute Percentage

Error), RMSE (Root Mean Square Error), and R^2 (coefficient of determination). Despite having a marginally higher MAPE (10.91%) than the quadratic model (9.09%), the cubic model exhibits the greatest R^2 value (0.94) for Area, suggesting a solid match. This implies that the quadratic model has marginally higher predictive accuracy, but the cubic model best explains the variation. The cubic model has the lowest MAPE (9.67%), making it the most dependable model for production forecasting, while the quadratic and cubic models both obtain an R^2 of 0.67, suggesting a decent fit. The R^2 values for the exponential and linear models are 0.19 and 0.26, respectively, indicating poor performance. With the highest R^2 (0.77) and the lowest MAPE (8.50%), the cubic model once again exhibits the best overall performance in terms of productivity. This demonstrates that, especially for long-term agricultural trend analysis, cubic regression better captures non-linear trends across all three variables.

CONCLUSION

For this study, we have selected two major millet crops, viz., pearl millet and finger millet. after analyzing all the parameters, we can say that the area of pearl millet shows a decreasing trend, while production and productivity show an increasing trend. In the case of finger millet, the area and production both show a decreasing trend, while the productivity of finger millet shows an increasing trend. For this study, we have selected some linear and nonlinear regression models to show the best-fitted model. After analyzing all the models, we can say the cubic regression model shows the best results for both crops, viz., pearl millet and finger millet.

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