The Andhra Agric. J 72 (2): 371-374, 2025
doi :10.61657/aaj.2025.222

Nonlinear modeling of crop production: A case study on jowar and greengram in Guntur district

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ABSTRACT

Guntur district in Andhra Pradesh is a key agricultural area known for its significant crop production. Nonlinear statistical growth models play a very important role in understanding the dynamics of an agricultural system. Present study made an attempt to develop nonlinear statistical growth models to describe trends of Production of Jowar and Green gram from Guntur district of Andhra Pradesh, by using 26 years of data i.e. from 1998-2023. Here, different statistical growth models viz., Power, Cubic, Richards, Gompertz, Logarithmic, Weibull, Hoerl, Exponential, MMF models were titled and comparative study was made for selecting best fitted models. By this study, Cubic and Weibull model were found to be quite successful for describing the growth pattern of Jowar and Green gram, based on selected diagnostic criterion and assumptions of residuals. Projection of production of Jowar and Green gram were found to be 12.63 ('000 tonnes) and 19.47 ('000 tonnes) by 2028 respectively.

Keywords: *Green gram, Jowar, MAPE, MAE, Nonlinear growth models, Production and RMSE*

Agriculture has been the backbone of the Indian economy for centuries and continues to play a vital role in the country's socio-economic development. It provides employment to nearly 45–65% of the population (Economic Survey 2023-24) and contributes significantly to the national GDP, although its share in the GDP has been gradually declining due to the rise of industry and services sectors.

Guntur district situated in the central coastal region of Andhra Pradesh in India, is one of the most agriculturally significant regions in the state. Guntur district is bordered by Krishna district to the north, Palnadu district to the west, Bapatla district to the south and the Krishna River to the east. The total cultivable area in Guntur district is about 2,19,548 ha of total geographical area (2.447 lakh ha), (https://guntur.ap.gov.in). Its diverse crop production, including significant quantities of tobacco, chilli peppers and cotton underscores its pivotal role in the country's agricultural landscape.

Jowar (*Sorghum bicolor* L.), commonly known as sorghum, is an important coarse cereal crop in India, valued for its resilience to drought and heat, making it highly suitable for semi-arid and rainfed regions. The crop covers an area of approximately 13 thousand hectares, with an annual production of around 82 thousand tonnes and an average yield of 6304 kg per hectare (Andhra Pradesh Agricultural statistics at a glance, 2023-24), highlighting its relevance in dryland farming systems and its contribution to sustainable agriculture in the region.

Green gram (*Vigna radiata* L.), commonly known as moong dal, is an important pulse crop in India, valued for its nutritional richness, particularly in protein and dietary fibre. Green gram is often grown in rotation with other crops like paddy or maize, helping to improve soil fertility due to its nitrogen-fixing properties. Green gram in Guntur district covers an area of approximately 10 thousand hectares with annual production of 12 thousand tonnes and yield of 1236 kg per hectare (Andhra Pradesh Agricultural statistics at a glance, 2023-24), underscoring its importance in sustainable farming and rural livelihoods.

Growth rate analyses are commonly used to describe the long-term trends in variables over time. Nonlinear growth models have widely been used to measure agricultural growth in terms of growth rate reported by Singh *et al.* (2025). From realistic perspective, the input output relationships among variables in agricultural sciences are inherently nonlinear as reported by Iquebal et al. (2013). Akter et al. (2023) forecasted the area, production and productivity of Onion in Bangladesh.

Keeping in view the importance of these selected crops, the present study has been undertaken to find out the production of Jowar and Green gram by application of nonlinear models.

MATERIALS AND METHODS

Data pertaining to production of Jowar and Green gram in Guntur are collected for period of 26 years as during 1998-2023, from secondary sources (Directorate of Economics and Statistics). With a view to identify the best pattern of production, the following statistical growth models were employed.

Cubic : Y_t = a + b*x + c*x^2 + d*x^3+e;
Exponential : Y_t = a*exp(b*t) + e;
Logarithmic : Y_t = a+b*ln(t) + e;
Power : Y_t = a*t^b +e;
Gompertz : Y_t = a *exp(-exp(b-c*t)) +e;
Logistic : Y_t = a/(1+b*exp(-c*t)) +e;
Hoerl : Y_t = a*(b^t)*(t^c) +e ;
Richard : $Y_{t=}$ a/(1 + exp(b-c*x))^(1/d) +e;
Cubic : Y_t = a + b*x + c*x^2 + d*x^3+e;
Weibull : Y_t = a - b*exp(-c*x^d) +e;
Morgan Mercer Flodin (MMF) : Y_t = (a*b+c*t^d)/(b+t^d) +e;

Where, Y_t is the production (quantity) observed during the time t; a, b, c, d, are the parameters, and e is the error term. As non-linear regression (NLR) case, parameter estimates can be obtained by the 'Method of least squares'. However, minimization of residual sum of squares yield normal equations which are nonlinear in the parameters.

Levenberg Marquardt (LM): This algorithm is widely adopted method for solving nonlinear least square problems. It effectively bridges the gap between the gradient descent and Gauss-Newton methods, combing their strengths to ensure reliable convergence while maintaining computational efficiency, especially in the later stages of iteration. Due to its robustness and reliability, the LM algorithm is integrated into most standard statistical software packages for nonlinear parameter estimation. In this study, the nonlinear regression procedure available in Curve expert was utilized to perform the analysis using the LM optimization technique.

The LM iterative method requires the specification of initial parameters estimates for the chosen model. Determining appropriate initial values is often one of the most challenging aspects of nonlinear parameter estimation. Inappropriate initial values will result in greater execution time, longer iteration and nonconvergence of the iteration. To overcome this issue and enhance the likelihood of achieving global convergence, multiple sets of initial values are tested at the beginning of the iterative process. The iteration continues until the reduction in the residual sum of squares between successive steps become negligibly small, indicating that model has reached an optimal fit.

In this present study, the best model is identified based on some of the diagnostic criterion. They are Co-efficient of Determination (R^2), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE). In addition to this, the best fitted models, to obtain the trend showed better diagnostic criteria in all the cases due to their model residuals has showed normality and randomness by their respective tests *i.e.,* Shapiro Wilk and Run test respectively. The overall analysis was done by using the Curve-expert software and Excel.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}$$

$$RMSE = \left[\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 / n \right]^{1/2}$$

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{Y_i - \hat{Y}_i}{Y_i} \right| \times 100$$

$$MAE = \frac{\sum_{i=1}^{n} |(Y_i - \hat{Y}_i)|}{n}$$

RESULTS AND DISCUSSION

The average production of Jowar in Guntur during the study period was 8.30 ('000) tonnes. Firstly, all selected models were applied to fit for Jowar and their estimated parameters were summarized in Table-1. The key residual assumptions of independence and normality for each selected model were assessed using the Run test and Shapiro Wilk test respectively. The corresponding p-values of these tests are reported in Table-1. These results indicated that for the Cubic model, the Run test was non-significant (p-value >0.05), suggesting that the residuals are independent. Similarly, the Shapiro Wilk test was also non-significant (p-value >0.05) for the model, confirming that the residuals follow a normal distribution. Hence, the assumptions of randomness of residual and normal distribution of residuals were satisfied. Based on performance of model fit and assumptions of residuals, Cubic model was identified as appropriate model for production of Jowar. This is consistent with the findings of Rao *et al.* (2021), who also reported that Cubic model was well suited for capturing the area and production of Wheat in India.

Then goodness of fit for the fitted model viz., R^2, RMSE, MAPE and MAE were computed to all models as shown in Table-1. From this, Cubic model was identified was best fit due to higher value of R^2 and minimum values of RMSE, MAE, MAPE. Therefore, Cubic model was identified as the best fit model for forecasting the production of Jowar and future projections are illustrated in Figure 1. The results showed a close alignment between the actual and predicted values, indicating a strong model fit. Based on the forecast, the production of Jowar is expected to increase by 12.63 ('000 tonnes) by 2028.

The average production of Green gram in Guntur during the study period was 5.88 ('000) tonnes/ha. As shown in Table 1, all the estimated parameter of the models were found to be statistically significant at the 5% level. However, the assumptions of normality and randomness of residuals were satisfactorily met. Among the nonlinear models, Weibull model is the best fit than other nonlinear models based on the model diagnostic criterion. This is consistent with the findings of Tanaskovic *et al.* (2025), who also reported that Weibull model was

Table-1: Goodness of fit and estimation of parameters for production of jowar and green gram

Model	Parameter Estimates				Model diagnostics					
	a	b	c	d	MAE	RMSE	MAPE	R^2	Run test	Shapiro Wilk test
Production of Jowar										
Cubic	4.39	1.44	-0.11	0.00	1.57	1.91	19.04	0.57	0.10	0.18
Exponential	9.05	-0.01			1.86	2.20	22.47	0.39	0.04	0.54
Logarithm	8.28	0.01			1.89	2.24	22.80	0.34	0.69	0.42
Hoerl	5.95	0.95	0.41		1.69	1.96	20.48	0.42	0.42	0.06
Power	8.28	0.00			1.89	2.24	22.80	0.36	0.69	0.42
Gompertz	8.48	-0.03	0.87		1.79	2.16	21.25	0.37	0.42	0.11
MMF	5.73	60.00	8.49	5.00	1.76	2.15	20.83	0.49	0.42	0.10
Richard	8.50	153.85	36.06	311.84	1.75	2.15	20.69	0.45	0.42	0.08
Weibull	8.47	12.85	1.52	0.72	1.80	2.16	21.37	0.52	0.42	0.14
Production of Green gram										
Cubic	3.35	-0.76	0.07	0	1.75	2.40	52.58	0.81	1.00	0.00
Exponential	0.84	0.02			4.94	7.23	414.49	0.72	0.03	0.00
Logarithm	-4.42	4.37			3.73	4.20	81.67	0.42	0.07	0.06
Hoerl	0.74	1.12	0.07		2.02	2.51	55.45	0.79	0.32	0.02
Power	0.01	2.25			1.96	2.52	658.77	0.80	0.84	0.02
Gompertz	195.19	1.86	0.04		1.94	2.48	80.88	0.80	0.84	0.01
MMF	-1.02	412.68	52.10	1.56	2.52	2.92	265.83	0.72	1.00	0.06
Weibull	20.23	18.87	0.00	3.90	1.75	2.40	49.35	0.81	0.84	0.06

* Significant at 5% level : Non-significant at 5% level.

well suited for capturing the area and production of Cotton in India. Accordingly, the actual and predicted exports of Green gram were modelled using the Weibull function, as depicted in Figure 2. Based on performance of model fit and assumptions of residuals, Weibull model was identified as appropriate model for production of Green gram. Then goodness of fit for the fitted model viz., R^2, RMSE, MAPE and MAE were computed to all models as shown in Table-1. From this, Weibull model was identified was best fit due to higher value of R^2 and minimum values of RMSE, MAE, MAPE. Therefore, Weibull model was identified as the best fit model for forecasting the production of Green gram and future projections are illustrated in Figure 2. The results showed a close alignment between the actual and predicted values, indicating a strong model fit. Based on the forecast, the production of Green gram is expected to increase by 19.47 ('000 tonnes) by 2028.

Fitting of nonlinear regression models for jowar and green gram in Guntur district

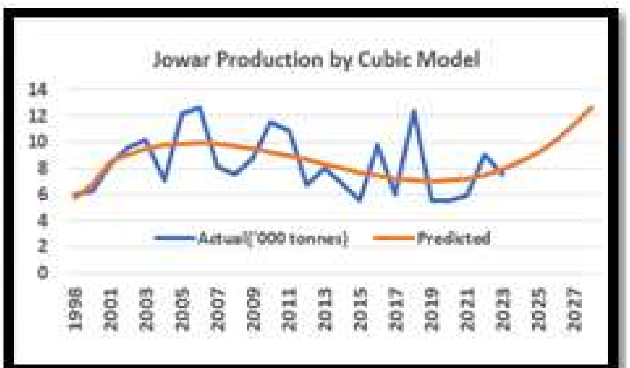

Figure-1. Graph of fitted cubic model along with observed

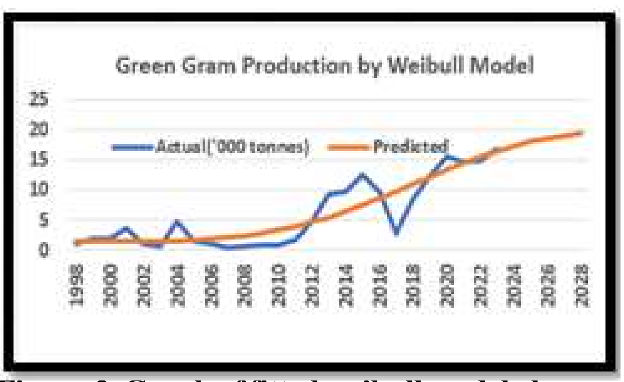

Figure-2. Graph of fitted weibull model along with observed

CONCLUSION

The present investigation has been undertaken for production scenario of Jowar and Green gram from Guntur to evaluate the growth rates during the study period of 1998 to 2023. From this study, it was observed that Cubic and Weibull model was appropriate for describing trends in Jowar and Green gram respectively. Finally, it has been concluded that in a few coming years, both of these productions will be going to increase. Timely management practices and effective extension systems are needed to create awareness among the farmers, regarding improved production technologies, various marketing and export channels to attain the production.

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Received on 12.08.2025 and Accepted on 18.09.2025