

Forecasting of Pulses crops in India: A Non Linear Approach

ABSTRACT

India is the world's top producer and consumer of pulses. Pulses are an essential source of protein, providing amino acids, vitamins and minerals to supplement diets. Pulses contain 22-24 percent protein, about twice as much as wheat. This research uses a non-linear growth approach to conduct an analytical evaluation of total pulse productivity in India from 1949-2020. For total pulse yield in India, four different non-linear growth models were fitted: Logistic, Gompertz, Monomolecular, and Von Bertalanffy. Goodness of fit statistics such as Coefficient of determination, Root Mean Square Error, Mean Absolute Error, and Mean Absolute Percentage Error were used to choose the best model. The Logistic model was determined to be the best fit for yield of total pulses grown in India, followed by the Gompertz model. Finally, the Logistic and Gompertz models were used to forecast India's total pulses yield from 2020-21 to 2025-26.

Keywords: Gompertz, logistic, monomolecular, non-linear growth model, von bertalanffy

INTRODUCTION

In India, pulses are the main source of nutrition. Pulses provide high-quality protein and roughage to a country with a large vegetarian population. Pulses are annual leguminous crops that produce 1-12 grains or seeds of various sizes, shapes, and color within a pod for use as food and forage. The term "pulses" refers to crops farmed solely for dry grain, which excludes vegetable crops as well as crops used primarily for oil extraction. India is the world's leading producer, consumer, and trader of pulses. Pulses are grown in both the Kharif and Rabi seasons, however Rabi pulses account for more than 60% of overall production. Between 1950 and 2018, India's pulse production climbed from roughly 8.4 million tonnes to 25.2 million tonnes. Pulses are the primary source of proteins that have been shown to lessen the risk of diseases including colon cancer and heart disease (Jukanti *et al.*, 2012). Pulses are the primary source of protein in the Indian

diet, and their demand is steadily increasing due to the rising population and affluence (Chauhan *et al.*, 2016). Pulses' net availability has decreased from 60 to 30 g/day/person between 1951 and 2014. Therefore, to meet the demand of pulses, India will require a continuous high growth in production.

Nonlinear growth models have been widely utilized to assess agricultural patterns in terms of rate of increase (Joshi and Saxena, 2002; Sarma, 2005; Rajarathinam *et al.*, 2010). Pal and Mazumdar (2015) investigated various nonlinear growth models, including Monomolecular, Logistic, and Gompertz models, to predict India's total groundnut production from 1950 to 2012. On the basis of multiple goodness of fit measures, Monomolecular and Logistic models outperformed Gompertz for their dataset. The best fitted model was used to forecast India's total groundnut production for 2014-20. Mata-Estrada *et al.*, (2020) compared the Gompertz-Laird, Logistic, Richards, and Von Bertalanffy growth models to examine the best fitted model on the data of Creole chickens. Analysis has been done using PROC NLIN to fit the non-linear growth curve. The Akaike information criteria, Bayesian information criteria and Coefficient of determination were used for the comparison of the goodness of fit of the models. The Von Bertalanffy was the best model for explaining growth of the birds. In contrast, both the Gompertz-Laird and Logistic models overestimated hatching BW and underestimated the final BW of CC. Rajan and Palanivel (2017) compared the goodness of fit of 6 non-linear growth models for cotton area, production and productivity data in India collected during 1982-2013. They found that Gompertz, Quadratic and Reciprocal are best fitted model. Panwar *et al.*, (2014) used a non-linear technique to examine at wheat yield in Uttar Pradesh. From 1970 to 2010, time series data on yearly wheat yields in Uttar Pradesh were gathered from a variety of sources. Non -linear models such as Logistic, Gompertz, and Monomolecular models are used to calculate growth rates. To estimate non-linear growth rates, several non-linear processes were employed, including the Steepest Descent Method, Gauss Newton Method, Do Not Use Derivative Method, and Levenberg Merquadt Technique. They observed that the Logistic model outperformed the Gompertz and Monomolecular models. Using statistical tools and approaches ranging from graphs, charts, and diagrams to regression and time series analysis, a variety of research have been started to understand the growing trend of pulses in India.

MATERIALS AND METHODS

The proposed research examined at the growth pattern of total pulses yield in India from 1949 to 2020. Indiastat.com has been used to obtain secondary data on total pulses. For estimating the growth in productivity of pulses, the study compared distinct non-linear growth models, such as Logistic, Gompertz, Monomolecular, and Von Bertalanffy. Selection criteria such as R^2 , Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE) were used to determine the best fitted model.

2. Linear and Non-linear models

The response of a linear model is proportional to the explanatory variables. All of the parameters in such models have a linear relationship. A non-linear model, on the other hand, is one in which the linear relationship for at least one of the parameters does not hold. Consider the following equations:

$$y = a + b * t \quad (1)$$

$$y = a + b * t + c * t^2$$

(2)

characterizes a linear model, whereas equation:

$$y = y_0 * \exp(-a * t)$$

(3)

represents a non-linear model. Two types of non-linear models are found in practice. The following are the equations:

$$y = \exp(a + b * t^2)$$

(4)

and

$$y = \exp(-b * t) - \exp(-a * t)$$

(5)

Even if, both these models are nonlinear in parameters a and b but they are basically of different characters. Equation (4) can be transformed into linear form by taking natural algorithm:

$$\ln y = a + b * t^2$$

(6)

which is linear in parameters. Because the model in equation (4) can be transformed into linear form, it is referred to as intrinsically linear. However, because Equation (5) cannot be converted to a linear form, it is referred to as an intrinsically non-linear model.

If it is not possible to solve the non-linear equations exactly in a non-linear model, iterative approaches are used to estimate the parameters. Steepest descent method, Linearization (Taylor series) method, and Levenberg-approach Marquardt's are all important iterative procedures for approximating analytical solutions. The Levenberg Marquardt technique is the most commonly used method for computing non-linear least square estimators since it always converges and does not slow down even at the end of the iterative process.

Important Non-linear Growth Models:

Logistic model

"Pierre Verhulst" devised a Logistic model that suggested that the rate of population growth may be limited, and that it may be dependent on population size. The parameters of the logistic model can be easily understood. This model generates an S-shaped curve and is most commonly employed in fields where growth is symmetric around the point of inflection. Hence the Logistic equation is as follows:

$$y = \frac{a}{(1+b*\exp(-k*t))}$$

(7)

where y represents growth at time t and a, b, and k represent the parameters. The parameters 'a' and 'k' denote carrying capacity, intrinsic growth rate, and different functions of the initial value, respectively.

Monomolecular model

The Monomolecular model describes the progression of a growth situation in which the rate of growth is considered to be proportionate to the remaining resources. The Monomolecular model is most commonly utilised in fields where the rate of growth declines linearly as size grows with no inflection point. Monomolecular model may be written as:

$$y = a * [1 - b * \exp(-k * t)]$$

(8)

Gompertz model

In 1825, Gompertz proposed the Gompertz model for hazard in life tables. The Gompertz model is widely utilised, especially in fields where growth is asymmetrical at the

point of inflection. The Gompertz model features sigmoid behaviour and has been proven to be very beneficial in biological processes. The Gompertz model is written as:

$$y = a * \exp(-b * \exp(-k * t))$$

(9)

Von Bertalanffy Model

Ludwig Von Bertalanffy proposed the Von Bertalanffy's model in 1957, which is a non-linear model with a sigmoidal shape that is not symmetrical in relation to the inflection point. The model was originally developed in the ecological field to simulate the growth of fish and crustaceans over time. The Von Bertalanffy model is written as follows:

$$y = a * [1 - b * \exp(-k * t)]^3$$

(10)

Initial Value Specification and Goodness of Fit

One of the most difficult problems in estimating parameters of non-linear models is initial value specification. The challenge of selecting initial values for parameters, on the other hand, can be overcome with a good understanding of the parameters' definitions in the context of the phenomenon being simulated. Wrong starting values lead to longer iterations, longer execution times, iteration non-convergence, and possibly convergence to an undesirable local minimum. There have been developed expressions that provide good starting values for some of the parameters (Borah and Mahanta, 2013). The order of a, b, and k is the most efficient for determining initial values.

The Initial value estimation using Solver

For estimation of the initial values, we have used solver program in excel by using the following steps:

- (i) Open the solver program in the data menu of excel.
- (ii) Put the initial value for parameter a, b and k as 1, 1 and 1.
- (iii) Select the Error Sum of Squares in Set objective.
- (iv) Select the minimization option.
- (v) Now select the parameter value in (ii) for changing variable cells option.
- (vi) Finally click on the Solve option.

Now these estimated initial values are used for fitting of non-linear growth models.

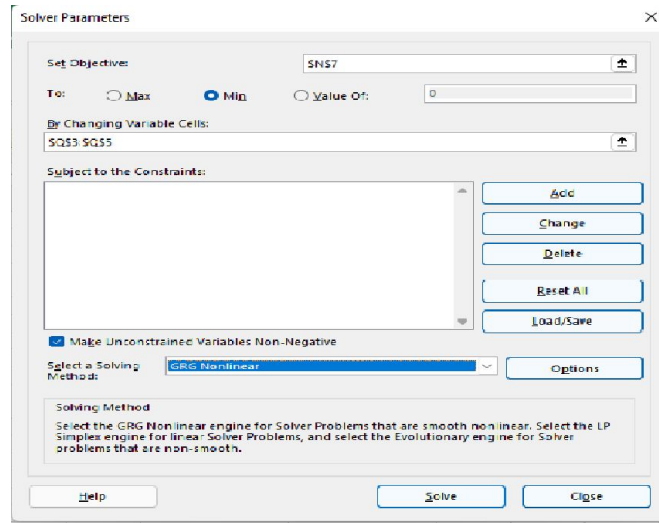


Image 1: Non-linear growth models

Goodness of Fit (GoF)

There is no single way for determining a model's quality of fit. The various elements of the data and model can be highlighted using a variety of approaches. The graphical comparison provides a quick visual examination of the GoF. The R^2 , RMSE, MAPE, and MAE are utilised as the GoF criterion to analyse the model's fit using the formula:

$$R^2 = 1 - \left(\frac{RSS}{TSS} \right)$$

(11)

where RSS is the residual sum of squares and TSS is the total sum of squares

$$RMSE = \sqrt{\frac{\sum (y - \hat{y})^2}{n}}$$

(12)

$$MAE = \sum \frac{|y - \hat{y}|}{n}$$

(13)

$$MAPE = \frac{100}{n} \sum \left| \frac{y - \hat{y}}{y} \right|$$

(14)

where y is the observed value and \hat{y} is the predicted value of total pulses yield.

RESULTS AND DISCUSSION

Initially, the goal was to find a non-linear growth model that best reflected the total pulses data of productivity in India. For the period 1949 to 2020 in India, various growth

models such as Logistic, Gompertz, Monomolecular, and Von Bertalanffy were considered for the modelling of productivity under total pulses. Table 1 shows the initial values for which the iterative technique converged, as well as estimated values following convergence of the total pulses.

Table: 1 Initial parameter values for different non-linear growth models

Parameters	Logistic	Gompertz	Monomolecular	Von Bertalanffy
A	7866.46	3243.15	2373.58	2644.97
B	17.93	2.07	0.83	0.46
K	0.008	0.004	0.002	0.003

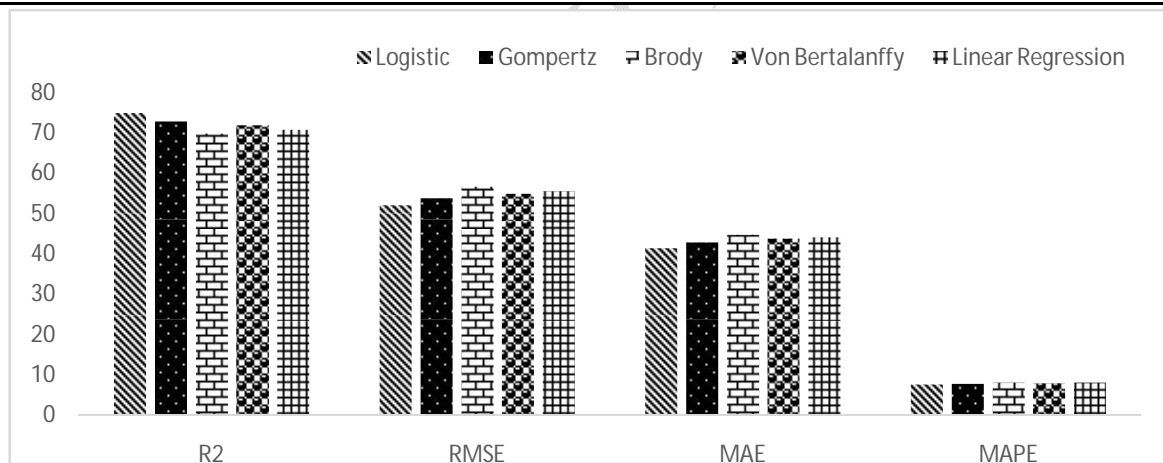


Fig. 1 Goodness of fit statistics

All four models have been well fitted to the specified dataset, as shown in Fig. 1. However, when the models were compared using GoF criteria, it was discovered that the Logistic and Gompertz models outperformed the others. On the basis of MAE, RMSE, and MAPE, logistic has a minimum value of 41.64, 52.15, 7.70, and Gompertz has a minimum value of 42.99, 54.02, 7.94. The maximum values for R² Logistic and Gompertz are 0.75 and 0.73, respectively. Figures 2 and 3 depict the best-fit logistic and Gompertz models, as well as the observed data value. The x-axis of the following graph represents

time, while the y-axis represents yield in million tonnes. The graphic shows that the observed and expected values for are very similar.

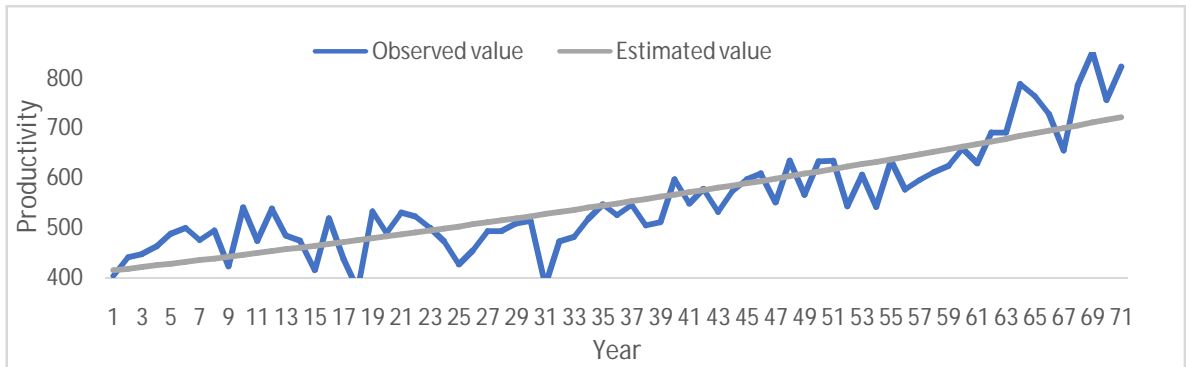


Fig:2 Observed vs Estimated values of total pulses yield for logistic model.

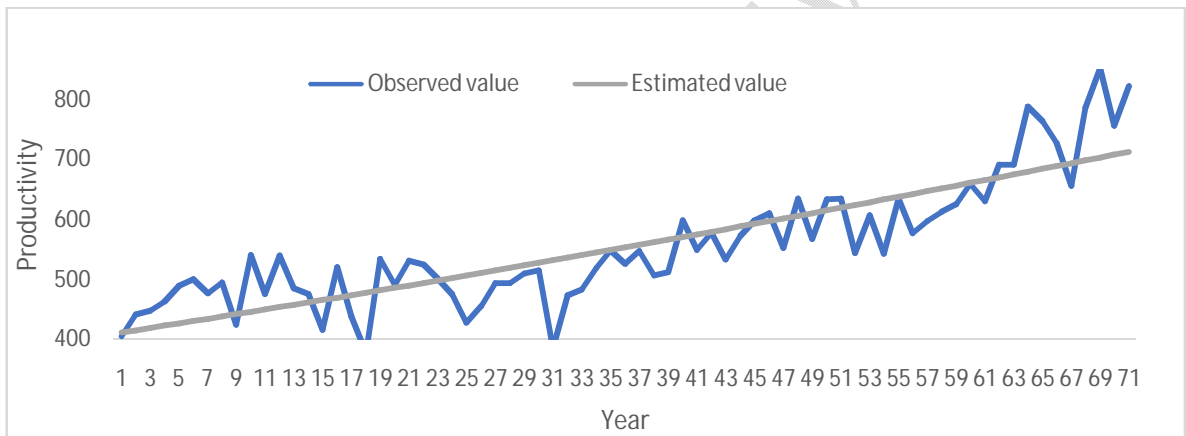


Fig: 3 Observed Vs Estimated values of total pulses yield for Gompertz model

It is clear from the GoF criteria that Logistic and Gompertz model outperform than other fitted models, therefore, forecasting of total pulses yield in India has been done by using these two models as shown in Fig. 4 and 5

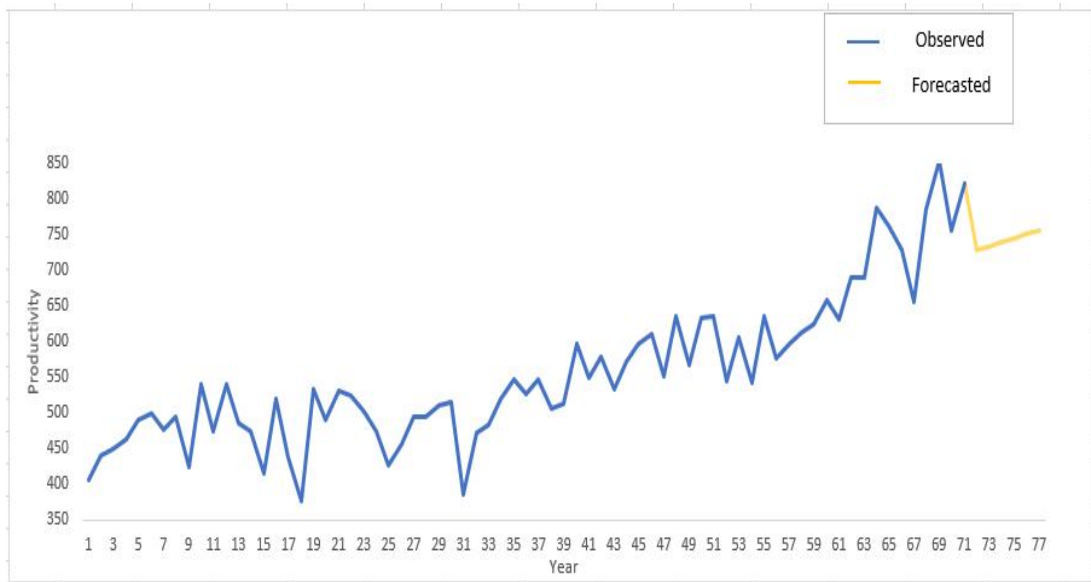


Fig: 4 Observed and Forecasted values of total pulses yield for Logistic model.

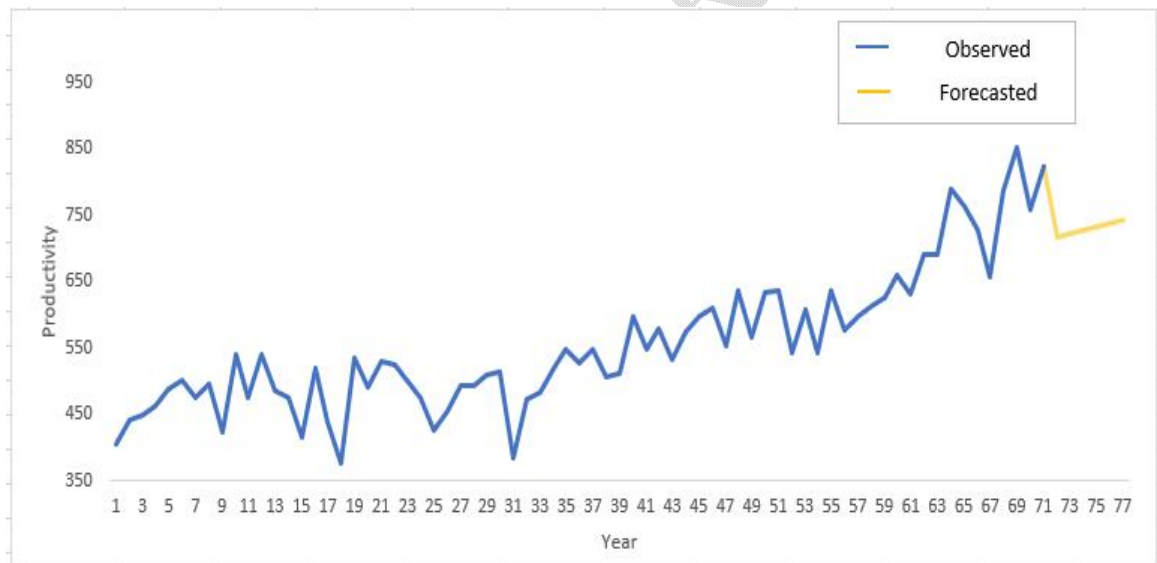


Fig: 5 Observed and Forecasted values of total pulses yield for Gompertz model.

For the period 2020-26, the yield of total pulses is expected to increase from 728.07 to 756.65 in the Logistic model and from 717.73 to 741.83 in the Gompertz model, according to forecasted values

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