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A Study on the Effectiveness of Linear and Non-Linear Models in Forecasting Area and Production of Potato in Himachal Pradesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study analyzed the trend in area and production of potato over a time period is important for understanding the past behavior and for future planning. The secondary data for study of area and production of potato from 1989-2024 were collected. Various statistical growth models viz. linear, quadratic, cubic, compound and power applied for area and production of potato in Himachal Pradesh. The study revealed that cubic model was found to best fitted model for production of potato and none model were found suitable for potato area. Highest value of CDVI for area is 9.65

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and production is 7.79 which indicate the higher level of instability in which variable is more erratic and less area over time. The decreasing annual growth rate for potato area is 0.2 percent and 1.5 percent with respect to production of potato over the studied period of time using compound model.

Keywords: compound model; CDVI; production; potato.

1. INTRODUCTION

Potato is perhaps the most wide-spread vegetable and India is second largest producer of potatoes in the world after China. India showed tremendous growth in potato production during last one and half decade (Rana and Anwer, 2018). In India, potato is cultivated across diverse agro-climatic zones, contributing significantly to rural livelihoods and the agricultural economy. Potato is grown over an area of 23.22 lakh hectare and Production is 589.94 Lakh Tonne (PIB, 2024). The crop's adaptability to varying climates and its compatibility with different cropping systems make it a valuable component in sustainable agriculture (Greeshma et al., 2017; Choudhury & Kalita, 2018).

In recent years, the increasing demand for processed food, coupled with rising population and urbanization has amplified the importance of potato in India's agricultural economy (Yadav et al., 2024; Kumar et al., 2025). Despite challenges like climate variability, pest outbreaks and post-harvest losses, the crop continues to offer significant potential for enhancing farmer income and strengthening India's agri-food system (Pandey et al., 2018). Himachal Pradesh occupies an important place in Potato map in India, the cultivating potato area is 15000 Hectare and production is 195000 tonnes (Anonymous, 2024). It is the cash crop of mid and high hills. Potato is the crop which holds promise to fill gap between food needs and cereal production in India

2. METHODOLOGY

In the present study, the time series data on area and production of Potato was collected from the directorate of Agriculture, Shimla, Himachal Pradesh, for the period 1989 to 2024. The data were analyzed by using R software for trend analysis.

2.1 Analytical Framework

The various statistical techniques were used to achieve the objective of the study

2.2 Forecast through Regression Models

Various linear and nonlinear regression models were used for trend analysis where the time is considered as an independent variable can be represented by the following equations:

i)	Linear	$Y_t = a + bt + e_t$
ii)	Quadratic	$Y_t = a + bt + ct^2 + e_t$
iii)	Cubic	$Y_t = a + bt + ct^2 + dt^3 + e_t$
iv)	Power	$Y_t = a \times t^b + e_t$
v)	Compound	$Y_t = a \times b^t + e_t$
vi)	Exponential	$Y_t = a \times e^{bt} + e_t$

where;

Y_t = time series values of dependent variable

t = independent variable, time element which takes the value 1, 2,…,n for various years.

a = intercept

b & c = regression coefficients

e_t = error term

2.3 Growth Rate

2.3.1 Linear growth rate

The linear growth rate

$$L\,G\,R = \frac{b}{\overline{Yt}} \times 100$$

Where,

b = regression coefficient of linear model

$\overline{Yt}$ = mean of predicted value by linear model

2.3.2 Compound growth rate

The compound growth rates for different variables were computed by fitting the exponential function to the figure of production of potato for the period of 1989 to 2024 of Himachal Pradesh. The ordinary least square method was used to fit the exponential function of the following form Y = ae^{bt}. It was converted into log linear function with the help of logarithmic transformation as under:

Ln Y = Ln a + b t.

Where,

Ln = Natural logarithm
Y = Dependent variable (Production or area)
t = Independent variable (time in a year)

2.4 Cuddy Della- Valle Index

Variability can be calculated from the simple coefficient of variation. However, it is often overestimated the level of instability in the time series data due to the presence of long-term trends, so the Cuddy Della Vella index was constructed to correct the flaws of present study.

CDVI = CV $\times \sqrt{1 - R^2}$
Where, CV = Coefficient of variation
R^2 = Coefficient of determination

2.5 Model Adequacy

The choice of the model amongst the available alternatives is judged on the basis of Goodness of fit is explained by R^2 and Adj. R^2 , minimum value of RMSE (Root mean square error), CV (Coefficient of variation) and Theil's Inequality.

$$R^2 = 1 - \left[\frac{\sum(yi - \hat{y}i)^2}{\sum(yi - \bar{y})^2}\right]$$

$$\bar{R}^2 = 1 - \frac{\frac{ESS}{(n-k-1)}}{\frac{TSS}{(n-1)}}$$

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

Where,

n = Number of observations.
Y_i = Actual value
$\hat{y}$i = Predicted value

3. RESULTS AND DISCUSSION

3.1 Potato Area Over Time

Table 1 that the prediction models namely: linear, quadratic, cubic, compound, power and exponential had statistically significant regression coefficients. The standard error and t- statistic values for the regression coefficient in these models are also shown. Table 2 shows that all these six models were not well fitted for the prediction of area under potato as R values range from (0.036 to 0.495) which was maximum in case of cubic model and the value of R^2 ranged between (0.001 to 0.245) . The values of $\bar{R}^2$ range from (-0.002 to 0.175) the negative and less value of $\bar{R}^2$ indicated that all the model were not best fitted. Lowest value of coefficient of variation was found to be 0.37 for power model which shows that the model is more consistent or has less variability.

Table 1. Coefficients, Standard error of coefficients, t- statistic of various models to Predict area under potato in Himachal Pradesh

Statistical Models		Coefficient	Standard Error	t-Statistic
Linear	a	14.683	0.574	25.570*
	b	0.027	0.027	1.006
Quadratic	a	15.148	0.900	16.835*
	b	-0.046	0.112	0.682
	c	0.002	0.003	0.504
Cubic	a	17.493	1.138	15.368*
	b	-0.758	0.263	-2.886
	c	0.049	0.016	3.018
	d	-0.001	0.000	-2.936
Compound	a	14.647	0.528	27.726*
	b	1.002	0.002	588.269*
Power	a	14.927	0.874	17.079*
	b	0.004	0.021	0.209
Exponential	a	14.647	0.528	27.726*
	b	0.002	0.002	0.971

**indicates significance at 5% level of significance*

Table 2. R, R^2, $\bar{R}^2$, RMSE and Coefficient of Variation (%) for the prediction models of area under potato

Statistical Models	R	R^2	$\bar{R}^2$	RMSE	C.V
Linear	0.170	0.029	0	1.68	1.88
Quadratic	0.205	0.042	-0.016	1.700	2.28
Cubic	0.495	0.245	0.175	1.53	5.50
Compound	0.164	0.027	0.002	0.104	1.73
Power	0.036	0.001	-0.028	0.109	0.37
Exponential	0.164	0.027	-0.002	0.104	1.73

On the basis of R, R^2, Adj. R^2, root mean square error (RMSE) and coefficient of variation (C.V.) no model was found to be best prediction model to forecast the area of potato among all the six prediction model because all the models have very less value of R, R^2 and $\bar{R}^2$, RMSE and CV. It is clearly been observed from the Fig. 1 that none of all six models trend line closed to actual potato area.

3.2 Potato Production Over Time

Table 4 shows that all these six models were fitted for the prediction of potato production as R values range from (0.836 to 0.883) which was maximum in case of cubic model and the value of R^2 ranged between (0.698 to 0.781) which was found highest in case of cubic model whereas it was lowest in case of power model. $\bar{R}^2$ values range from (0.689 to 0.765) in this highest value was found in quadratic model whereas lowest value was found in case of compound and exponential model. Lowest RMSE value was found to be 13.49 for the cubic model and it was highest in case of exponential model. Lowest value of coefficient of variation was found to be 13.59 for cubic model which shows that the model is more consistence or less variability and reflected good power of these models for prediction of potato production.

On the basis of R, R^2, $\bar{R}^2$, RMSE and Coefficient of variation cubic model was found to be the best prediction model to forecast the production of potato among all six prediction models because quadratic model has highest values of R (0.883), R^2 (0.781) and $\bar{R}^2$ (0.765) and has the lowest value for RMSE (13.49) and coefficient of variation (13.59%) which has in close affinity with the finding of number of blazes and resin yield of Chir pine in Himachal Pradesh state by Kumar (2023) and trends of area, production and productivity of turmeric in Assam by Chaudhary and Kalita (2018).

It can be clearly observed from the Fig. 2 that the observed and predicted value of potato production is closed in case of cubic model as compared to other five models.

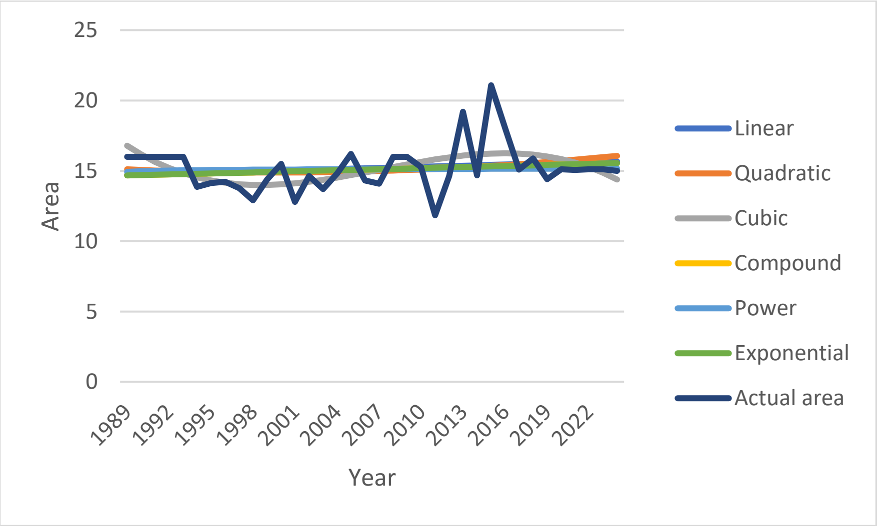

Fig. 1. Trend values of actual and predicted values of all six models for potato area in Himachal Pradesh

Table 3. Coefficients, Standard error of coefficients, t- statistic of various models to Predict potato production in Himachal Pradesh

Statistical Models		Coefficient	Standard Error	t-Statistic
Linear	a	124.729	4.788	10.154*
	b	2.291	0.226	26.051*
Quadratic	a	113.863	7.139	15.95*
	b	4.007	0.890	4.504*
	c	-0.046	0.023	-1.988*
Cubic	a	117.689	10.129	11.619*
	b	2.845	2.338	1.217
	c	0.031	0.146	0.213
	d	-0.001	0.003	-0.538
Compound	a	126.151	4.058	31.089*
	b	1.015	0.002	659.627*
Power	a	104.249	5.644	18.470*
	b	0.172	0.019	8.869*
Exponential	a	126.151	4.058	31.089*
	b	0.015	0.002	9.503*

**indicates significance at 5% level of significance*

Table 4. R, R^2, $\bar{R}^2$, RMSE and Coefficient of Variation (%) for the prediction models of potato production

Statistical Models	R	R^2	$\bar{R}^2$	RMSE	C.V
Linear	0.867	0.752	0.745	14.06	14.44
Quadratic	0.882	0.779	0.760	13.63	14.69
Cubic	0.883	0.781	0.765	13.49	13.59
Compound	0.852	0.726	0.718	14.09	15.14
Power	0.836	0.698	0.689	14.10	14.71
Exponential	0.852	0.726	0.718	15.94	15.14

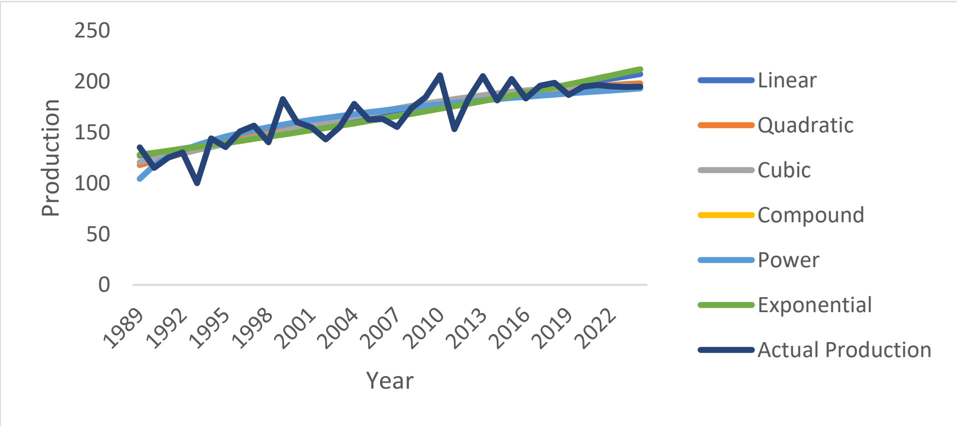

Fig. 2. Trend values of actual and predicted values of quadratic model for all six models of potato production in Himachal Pradesh

Table 5. Trends in area and Production of potato during 1989 – 2024

	Average	CDVI	LGR	CGR
Area (ha)	15186.42	9.65	0.17	0.2
Production (MT)	167120.1	7.79	1.37	1.5

The Table 5 represent the average potato area and production for the study period is 15186.42 ha and 167120.1 MT, respectively. Highest value of CDVI for area is 9.65 and production is 7.79 which indicate the higher level of instability in which variable is more erratic. The decreasing annual growth rate for potato area is 0.17 and 0.2 percent and 1.37 and 1.5 percent with respect to production of potato over the studied period of time using linear and compound model which is close affinity with prices and arrival in major apple markets of India by Shilpa and Sharma, 2021.

4. CONCLUSION

The present study regression parameter for estimating of cultivated potato area and production in Himachal Pradesh. Appropriateness of the model was judged by the magnitude and sign of the parameter estimates, goodness of fit (Goodness of fit is explained by R^2 and Adj. R^2 , minimum value of RMSE (Root mean square error) and CV (Coefficient of variation). The developed regression model for potato production was cubic regression models was found to best fitted for Himachal Pradesh for the study period with decreased trend and none model found suitable for prediction of potato area. These regression models were used for the prediction of area and production of potato in Himachal Pradesh. The average potato area and production for the study period is 15186.42 ha and 167120.1 MT, respectively. Highest value of CDVI for area is 9.65 and production is 7.79 which indicate the higher level of instability in which variable is more erratic and less area over time. The decreasing annual growth rate for potato area is 0.2 percent and 1.5 percent with respect to production of potato over the studied period of time using compound model. This model is used to study the trend and also for the future forecasting and prediction of potato area and production in Himachal Pradesh.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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