ISSN (online): 2320-9836
ISSN (Print): 2320-9828

Comparative evaluation of different statistical models for explaining productivity trend of rice and wheat crops in North Gujarat zone

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Abstract

Objective: To identify the appropriate trend equations, compound growth rates and instability indices of productivity of rice and wheat crops in North Gujarat zone in India.
Methods: The present study was made through fitting of different linear, non-linear and time series models. The time-series data from 1960-61 to 2012-13 on productivity of rice and wheat crops for North Gujarat zone were collected from Directorate of Agriculture, Gujarat state, Gandhinagar.
Findings: It was found that among different polynomial models, linear model for rice and cubic model for wheat were best fitted for productivity trend and in case of ARIMA models, ARIMA (0,1,1) was evolved as the best fitted trend functions for productivity of both rice and wheat crop. The compound growth rates for productivity were 6.65% and 3.99 % annually in rice and wheat crop, respectively. The instability indices were observed 24.72 with 44.49% CV in rice and 14.18 with 25.47% CV in wheat crop.
Improvements: The trend of productivity for different crops is important factor for successful planning and decision making for the policy makers. Forecasting also plays a crucial role in agricultural, business, industrial, government and institutional planning because many important decisions depend on the anticipated future values of certain variables.

***Keywords* :** ARIMA, polynomial models, compound growth rates, instability indices, trend

1. Introduction

Agriculture is one of the most important components of Indian economy.Last four decades have been an era of revolution in agriculture, especially in the field of crop production, which has brought a spectacular change in the existing cropping systems. The population of country is growing at an enormous speed and therefore, it is of paramount importance to achieve an enhanced rate of productivity of crops in order to keep pace with the growing population through better planning for optimum utilization of scare inputs such as land, capital, human and other natural resources. Since, agriculture is a vital sector of economy, even among highly industrialized countries, much care and expenditure are devoted to compilation of agricultural statistics.

In 2012-13, in Gujarat state production of rice was 14.79 lakh tonnes and the production of wheat was 29.44 lakh tonnes, the productivity of rice during the period was 2136 kg/ha and the productivity of wheat was 2876 kg/ha [1]. Crops are severely affected with abiotic factors e.g. rainfall, humidity and other environmental factors and biotic stresses such as diseases and pest infestation which also indirectly depends upon environment. The observation on these time series variables are varying in some pattern due to the existence of artificial and natural forces. The policymakers, while formulating policies have to keep in mind the shifting pattern and stability of crops for formulating the strategic all round developmental plan for zone, state or a country. The present investigation was therefore undertaken:to study fluctuation in productivity for rice and wheat crops through different models viz., Linear, Quadratic, Cubic, Exponential, Gompertz and Autoregressive Integrated Moving Average (ARIMA), along with their instability index.

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2. Materials and Methods

The time series data on productivity had some missing observations. Therefore, the simple moving average concept was utilized to find out missing observations. Three year simple moving averaging technique was found best for missing values during model development stage[2]. There was a severe drought caused by the failure of south-west monsoon over major parts of India during the year 1987 [3]. Therefore, the observations of productivity of the year 1987-88 for both the crops, were excluded from analysis of trends and compound growth rates. The following models were fitted for productivity of rice and wheat crops.

List of linear and non-linear models

Model No.	Model	Name of the Model
I.	Y=A+B*X	Linear equation
II.	$Y=A+B*X+C*X^2$	Second degree polynomial
III.	$Y=A+B*X+C*X^2+D*X^3$	Third degree polynomial
IV.	Y=A*exp(B*X)	Exponential model
V.	Y=A*exp(-exp(B-C*X))	Gompertz model

Where, Y is the productivity and X is the time points.

Among linear and non-linear models, the model having highest adjusted R^2 with significant F value. Which satisfies test for goodness of fit was selected. In the case of time-series models at first the conditions of stationarity was checked and then different ARIMA models were tried. Among the ARIMA models, the model having less Akaike's Information Criterion (AIC) and Bayesian Information Criterions (BIC) as well as the significant values of estimated parameters was considered as the best fitted model. The selected model was further tested for randomness and normality of error terms. In case of more than one model having the good fit for the data, the best model was selected having lower values of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE).

The compound growth rate (CGR) was calculated by fitting the exponential function given below

$Y= a*b^X$ ……………………………. (1)

Where, Y = Productivity, a=Constant,
b = Regression co-efficient, X= Time variable
Thus natural log on both the sides of equation (1) was taken to convert it in to linear form.
Log Y = log a + X log b ……………………………. (2)
CGR (%) was worked out by using following formula:
CGR (%) = (Anti log of b – 1) * 100 ……………………………. (3)

The simple co-efficient of variation (CV %) often contains the trend component and thus over estimates the level of instability in time series data characterized by long-term trends. To overcome this problem, this study used the Cuddy Della Valle index which corrects the CV by:

Instability Index = $(CV\ \%) * \sqrt{(1 - R^2)}$ …………………. (4)

Where, CV% = co-efficient of variation and R^2= co-efficient of determination from a time trend regression adjusted by the number of degrees of freedom.

3. Results and Discussion

3.1. Trend for rice crop

In [4],the results (Table 1) of five fitted models revealed that the linear model fulfilled all the model selection criteria and found suitable to fit the trend in productivity of the rice crop (Figure1), also found linear model for productivity of tobacco crop in Gujarat for the period from 1951-1952 to 1990-1991 as best fitted model. Gompertz non-linear model could not be fitted due to the fact that the parameters were found to be non-convergent. In ARIMA time-series methodology the auto-correlation up to fourteen lags were worked out. Since the computed auto-

ISSN (online): 2320-9836
ISSN (Print): 2320-9828

correlations γk values did not tail off towards zero, the original series was found to be non-stationary. The non-stationarity was also confirmed by examining the realization visually.It was found that the mean and variance were changing over the time. However, the stationarity was achieved by differencing one time i.e., d=1. The pattern of auto-correlations γk showed damped sine-wave and significant partial auto-correlations ϕkk at first and third lags. This suggested consideration of ARIMA(0,1,1), ARIMA(2,1,0) and ARIMA(3,1,0) as the candidate models and the results are given in Table 2.The assumptions of residuals i.e. normality and independence of residuals as tested by Shapiro-Wilk test (S-W Test) and Box-Ljung (BLQ) test indicated that all ARIMA models satisfied the assumption of normality and independence of residuals. ARIMA (0,1,1) model was found suitable to fit the trends in productivity of the rice crop among the ARIMA families' of time series models with 75.48 per cent R^2 value.

Figure 1. Trends in productivity of rice crop for North Gujarat zone based on linear regression model

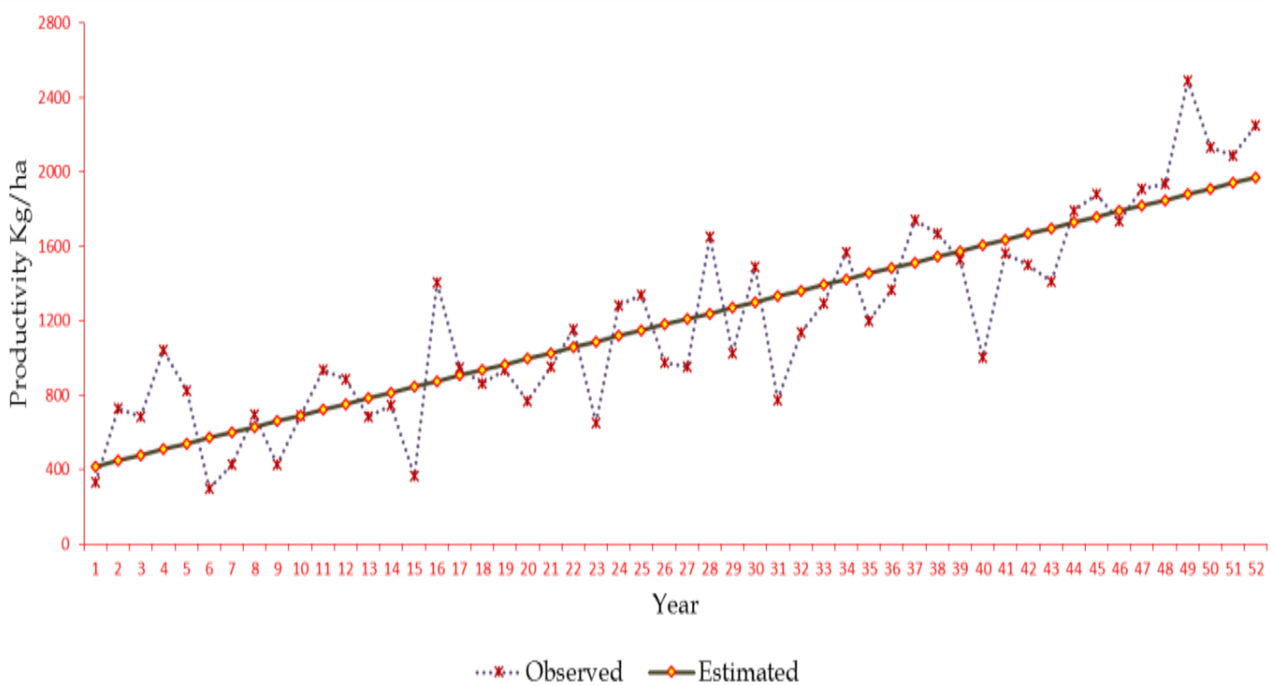


Table 1. Characteristics of fitted linear and non-linear models for productivity of rice and wheat crop for North Gujarat zone

Crop	Model	Regression constant	Partial regression co-efficient			Goodness of fit				
						Adj. R^2 (%)	S-W Test	Run Test (|Z|)	RMSE	MAE
		A	b	C	D					
Rice	Linear	386.733**	30.467**	-	-	75.04**	0.984	0.840	260.244	209.435
	Quadratic	612.265**	5.408	0.473**	-	77.94**	0.989	0.280	242.205	184.040
	Cubic	506.610**	28.249	-0.594	0.013	77.96**	0.984	0.840	248.981	201.375
	Exponential	512.906**	0.028**	-	-	69.13**	0.989	0.280	245.541	193.675
	Gompertz	-	-	-	-	-	-	-	-	-
Wheat	Linear	1339.830**	31.325**	-	-	73.23**	0.994	3.081**	280.447	228.697
	Quadratic	959.130**	73.623**	-0.798**	-	81.65**	0.976	0.840	229.843	177.744
	Cubic	640.358**	142.537**	-4.018**	0.041**	85.35**	0.983	0.560	203.236	157.606
	Exponential	1344.013**	0.017**	-	-	69.00**	0.981	6.162**	322.145	270.578
	Gompertz	-	-	-	-	-	-	-	-	-

* Significant at 5% level, ** Significant at 1% level

ISSN (online): 2320-9836
ISSN (Print): 2320-9828

Table 2. Characteristics of fitted time-series models for productivity of rice and wheat crop for North Gujarat zone

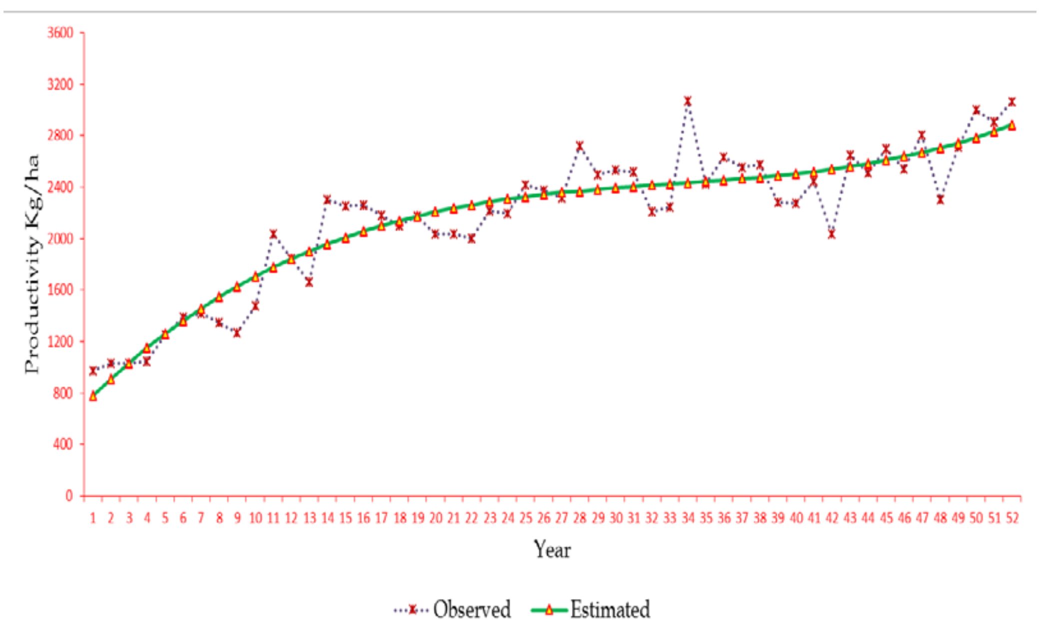
Crop	ARIMA p,d,q	Constant	AR (ϕ)			MA (θ)		AIC	BIC	S-W Test	BLQ Test	RMSE	R^2 (%)
			ϕ_1	ϕ_2	ϕ_3	θ_1	θ_2						
Rice	(0,1,1)	5.0025	-	-	-	0.987*	-	720.632	724.495	0.990	20.471	263.933	75.48
	(2,1,0)	12.153	-0.659**	0.329*	-	-	-	731.680	737.476	0.988	25.891	309.050	67.01
	(3,1,0)	2.183	-0.782**	-0.558**	-0.329*	-	-	729.084	736.811	0.987	27.222*	296.784	70.23
Wheat	(0,1,1)	0.904	-	-	-	0.600**	-	704.387	708.250	0.967	8.604	238.833	80.62
	(1,1,0)	0.852	-0.422	-	-	-	-	708.345	712.209	0.939*	14.962	249.735	78.81

* Significant at 5% level, ** Significant at 1% level

3.2. Trend for wheat crop

In [5] The result of productivity of the wheat cropTable 1 revealed among the fitted models, the cubic model had significant partial regression coefficients and non-significant S-W and run test, hence found suitable to fit the trend in productivity of the wheat crop figure 2, also found cubic model for wheat productivity in eastern Haryana. Gompertz non-linear model could not be fitted due to the fact that the parameters were found to be non-convergent. For the productivity trends ARIMA (0,1,1) model Table 2 was found suitable to fit the trends among the ARIMA families' of time series models with 80.62 per cent R^2 value. In[6] had also reported that ARIMA (0,1,1) model as the best fitted model for productivity of cereals in India.

Figure 2. Trends in productivity of wheat crop for North Gujarat zone based on cubic regression model



3.3. Compound growth rates and Instability indices

The results of compound growth rates of rice and wheat crops(Table 3) revealed that 6.65% and 3.99% per annum, respectively. It may be due to high yielding varieties and adoption of new technology. The instability indices were observed 24.72 with 44.49% CV in rice and instability index 14.18 with 25.47% CV in wheat crop. The values of R^2 were remain same as about 69 % in both the crops.

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Table 3. Compound growth rates and instability indices of productivity of rice and wheat crops for North Gujarat zone

Crop	CGR (% p.a.)	Instability Index	CV%	R^2
Rice	6.65*	24.72	44.49	0.6913
Wheat	3.99*	14.18	25.47	0.6900

* Significant at 5% level

4. Conclusion

In case of polynomial models, linear model was best fitted and in case of ARIMA models, ARIMA (0,1,1) was evolved as the best fitted trend functions for productivity of rice crop. Cubic model was found fitted for trends in productivity of wheat crop. ARIMA (0,1,1) was evolved as the best fitted trend functions for productivity of wheat crop. Increase in government funding to agriculture, selection of high yielding varieties, increase agricultural linkage between farmers and research institutes are important reasons behind the positive and significant compound rates in productivity of both the crops.

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The Publication fee is defrayed by Indian Society for Education and Environment (www.iseeadyar.org)

Cite this article as:

R. L.Yadav, A. D. Kalola. Comparative evaluation of different statistical models for explaining productivity trend of rice and wheat crops in North zone. *Indian Journal of Economics and Development*. Vol 4 (4), April 2016.