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Nonlinear approach for rice crop yield forecasting in Navsari district of Gujarat

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Abstract
Accurate forecasting of rice crop yield is crucial for efficient agricultural planning, resource allocation, and food security. This study introduces a different nonlinear approach for predicting rice crop yields (kg/ha) in the Navsari district of Gujarat. Traditional linear methods often struggle to capture the intricate relationships between crop yield and multifaceted environmental factors. The methodology involves the integration of historical rice yield data for the years 1985-2014. To evaluate the proposed approach, different nonlinear growth models have been applied on rice production data. The validation of the best-fitted models was carried out using data from 2012 to 2014. The results demonstrate the superiority of the nonlinear model in comparison to conventional linear models. The study indicated that linear and nonlinear models play significant role in rice yield forecast. The good fit of the model indicated a change of trend in rice yield which helps formulate price and market availability.

Keywords: Linear model, nonlinear model, rice, forecasting

Introduction

Agricultural productivity and food security are paramount concerns in today's world, particularly in regions heavily dependent on crop cultivation. In this context, the accurate forecasting of crop yields plays a pivotal role in effective resource management, policy formulation, and sustainable agricultural practices. The Navsari district in Gujarat, India, renowned for its rice cultivation, faces the challenge of predicting rice crop yields with precision due to the intricate interplay of numerous factors that influence agricultural outcomes.

The current scenario in the Navsari district underscores the need for a more sophisticated and accurate approach to rice crop yield forecasting. Fluctuations in weather patterns, changing agronomic practices, and evolving soil conditions pose challenges that require a deeper understanding of the underlying dynamics. Linear models, constrained by their inherent simplicity, struggle to account for the intricate web of nonlinear relationships that shape rice yield variations. Crop yield forecasts are typically assessed using parametric models that assume linear or exponential functional forms (Garde *et al.* 2020) [7]. Several researchers, including Kumar and Rosegrant (1994) [10], Kumar (1997) [9], Joshi and Saxena (2002) [8], Singh and Srivastava (2003) [13], Shah *et al.* (2005) [12], and Garde *et al.* (2012, 2015, 2020) [6, 5, 7], have employed these parametric models to forecast the crop yield and growth rates. However, it is possible that the actual data does not conform to these linear or exponential models and might necessitate the fitting of higher-degree polynomials or non-linear models. Bates and Watts (1988) [1] explained nonlinear regression analysis approaches. Nonparametric regression approach adopted for Computation of growth rates in agriculture by Chandran & Prajneshu (2004) [2] and Marquardt, (1963) [11].

Data and Methodology

The present study was carried out in the Navsari, district of South Gujarat. Considering the specific objectives of the study, Kharif rice yield data of 30 year (1985-2014) was collected from Directorate of Economics and Statistics (www.eands.dacnet.nic.in) and report of Directorate of Agriculture, Gujarat State, Gandhinagar (http://agri.gujarat.gov.in). The graphical representation of data used presented in Fig 1.

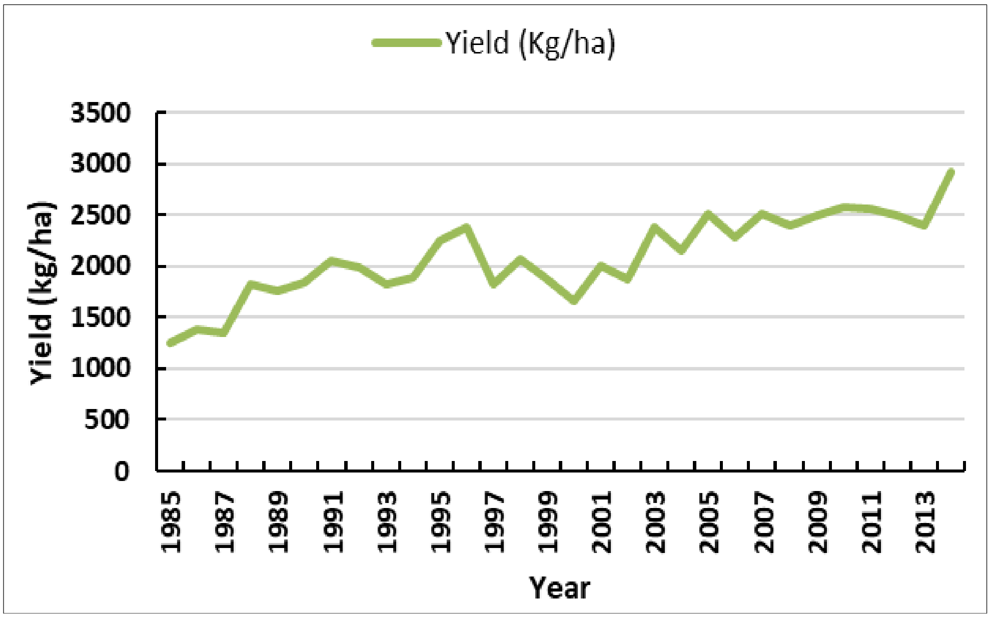


Fig 1: Trends in of rice crop yield (kg/ha)

Statistical data analysis

A mathematical model comprises an equation or a group of equations that depict the dynamics of a system. These models can assume the form of either linear or nonlinear representations. A linear model entails parameters that are employed in a linear fashion. It is widely acknowledged that any statistical investigation heavily influenced by principles from a particular knowledge domain is prone to yield a nonlinear model. These models are particularly valuable for comprehending intricate connections between variables. A nonlinear model, on the other hand, involves at least one parameter that operates in a nonlinear manner.

The current investigation delved into diverse methodologies for fitting both linear and nonlinear models to rice yield data spanning from 1985 to 2014. The process of model formulation encompassed a dataset spanning 27 years (1985-2011), with the subsequent validation of the model conducted using the remaining 3 years of data. The different models were tried on data are presented in the Table 1.

Table 1: Different developed linear and nonlinear model equations

Model Name	Form Model Equation	Developed model equation	R^2
Linear	$y = a + bx$	$y = -76351.403 + 39.23 * x$	0.682
ARIMA (1,1,0)	$\hat{Y}_t = \mu + Y_{t-1} + \phi_1 (Y_{t-1} - Y_{t-2})$	Const: 50.979; AR: -0.509; Diff: 1.000	0.569
Rational	$y = \frac{a + bx}{1 + cx + dx^2}$	$y = \frac{-7.08E_{+7} + 35918.7 * x}{1 - 8.81 * x + 0.005 * x^2}$	0.693
Logistic Power	$y = a/(1 + (x/b)^c)$	$y = \frac{3485}{\left(1 + \left(\frac{x}{1991}\right)^{-93.78}\right)}$	0.686
Heat Capacity	$y = a + bx + c/x^2$	$y = 1.08E_{+6} + 347.6 * x - \frac{(1.54E_{+12})}{x^2}$	0.690
Ratkowsky	$y = a/(1 + e^{b - cx})$	$y = \frac{3469.9}{(1 + e^{94.0 - 0.047 * x})}$	0.688
Natural Logarithm (Exp)	$y = a + b\ln(x)$	$y = -5.94E_{+5} + 78392\ln(x)$	0.688
Modified Power	$y = ab^x$	$y = 5.22E_{-14} * 1.019^x$	0.682
Reciprocal Quadratic YD	$y = x/(a + bx + cx^2)$	$y = \frac{x}{(1101.83 + -1.083 * x + 0.00027 * x^2)}$	0.682
Richards	$y = \frac{a}{(1 + e^{b - cx})^{1/d}}$	$y = \frac{18232.971}{(1 + e^{14.66 - 0.009 * x})^{\frac{1}{0.018}}}$	0.685
MMF Sigmoidal	$y = \frac{ab + cx^d}{b + x^d}$	$y = \frac{-2.67E_{+5} * 188.81 + 173640 * x^{0.75}}{188.81 + x^{0.75}}$	0.688
Bleasdale Yield Desity	$y = x(a + bx^{\theta})^{-1/\theta}$	$y = x * (38.18 \pm 32.22 * x^{0.019})^{\frac{-1}{0.019}}$	0.682
Modified Exponential	$y = ae^{b/x}$	$y = 8.07E_{+19} * e^{\frac{-76383}{x}}$	0.682
Exponential	$y = ae^{bx}$	$y = 5.22E_{-14} * e^{0.019 * x}$	0.682
Exponential Decline	$y = q_0 e^{-x/a}$	$y = 5.22E_{-14} * e^{\frac{-x}{-52.32}}$	0.682

Hyperbolic Decline	$y = q_0(1 + bx/a)^{(-1/b)}$	$y = 8.78E_{-10} * \left(1 + \frac{0.019 * x}{-91.72}\right)^{\frac{-1}{0.019}}$	0.682
Bleasdale Yield Spacing	$y = (a + bx)^{-1/c}$	$y = (1.173 + -1.09E_{-4} * x)^{\frac{-1}{0.006}}$	0.682
Firajdaghi Harris YD	$y = x/(a + bx^{\gamma})$	$y = \frac{x}{(808.903 - 576.72 * x^{0.044})}$	0.675
Modified Geometric	$y = ax^{b/x}$	$y = 2.64E_{+22} * x^{\frac{-11572}{x}}$	0.682
Saturation Growth Rate	$y = ax/(b + x)$	$y = \frac{-55.81 * x}{(-2053.9 + x)}$	0.675
Reciprocal YD	$y = x/(a + bx)$	$y = \frac{x}{(36.80 - 0.018 * x)}$	0.675
Reciprocal Logarithm	$y = \frac{1}{a + b\ln(x)}$	$y = \frac{1}{0.140 - 0.018\ln(x)}$	0.675
Reciprocal	$y = 1/(a + bx)$	$y = \frac{1}{(0.019 - 9.20E_{-6} * x)}$	0.674
Harmonic Decline	$y = q_0/(1 + x/a)$	$y = \frac{52.95}{(1 + \frac{x}{-2052.5})}$	0.674
Sinusoidal	$y = a + b\cos(cx + d)$	$y = -30530 + 33929 * \cos(0.004 * x + 475.2)$	0.690
Steinhart Hart Equation	$y = \frac{1}{A + B\ln(x) + C(\ln(x))^3}$	$y = \frac{1}{63.77 - 12.58 * \ln(x) + 0.073 * (\ln(x))^3}$	0.653
Gaussian	$y = ae^{\frac{-(x-b)^2}{2c^2}}$	$y = 3257.43 * e^{\frac{-(x-2046.3)^2}{2*49.86^2}}$	0.686

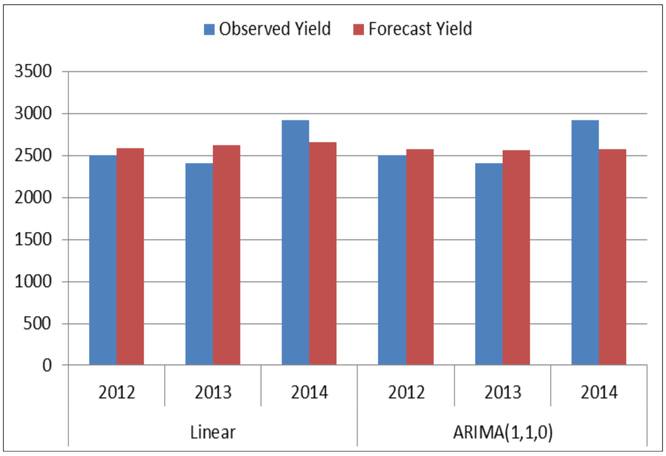
* *x* is year (*t*)

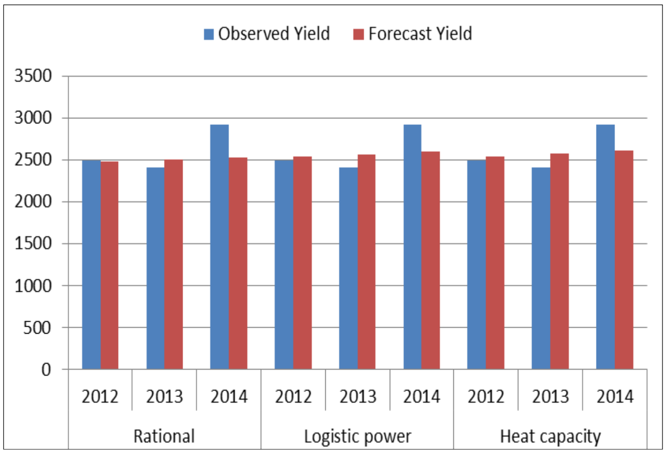
Result and Discussion

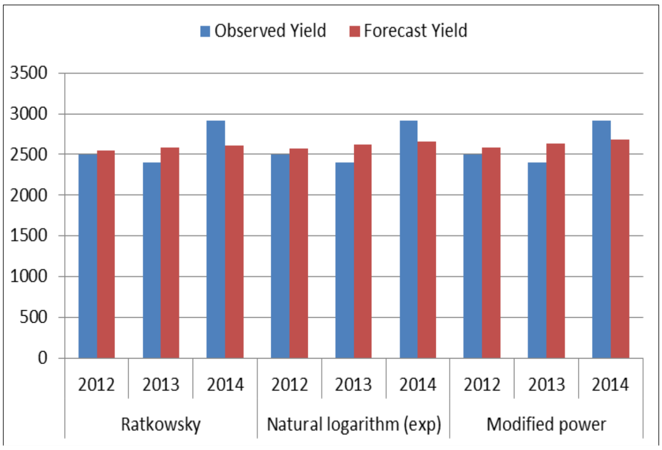
In the present study forecast yield was computed using developed models. Each model showed significant role in forecast of rice yield. The comparison of the model was carried out using value of R^2, % deviation, RMSE and MAPE. Based on the analysis all linear and nonlinear model developed were showed near about 0.59 to 0.70 R^2 value. Rice yield forecasting using Rational, Logistic power, Heat capacity and Ratkowsky model indicated minimum of value of MAPE i.e. 6.09 to 6.68 along with per cent deviation values 0.62 to -2.13. The details of the comparison are given in the Table 2. The graphical presentation of observed yield and forecast yield are given in Fig. 2

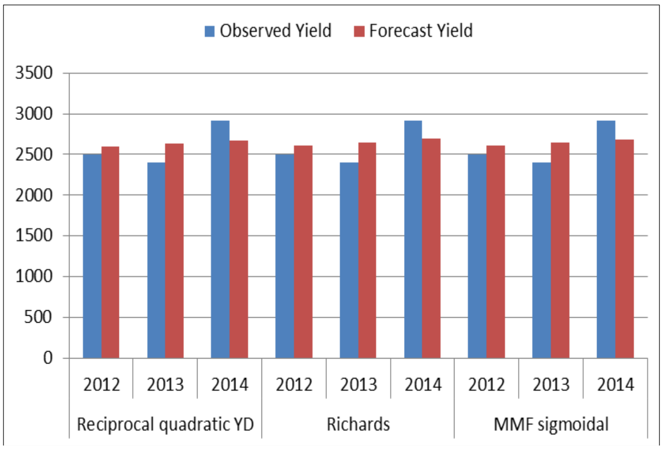
Table 2: Comparisons of the developed linear and nonlinear models

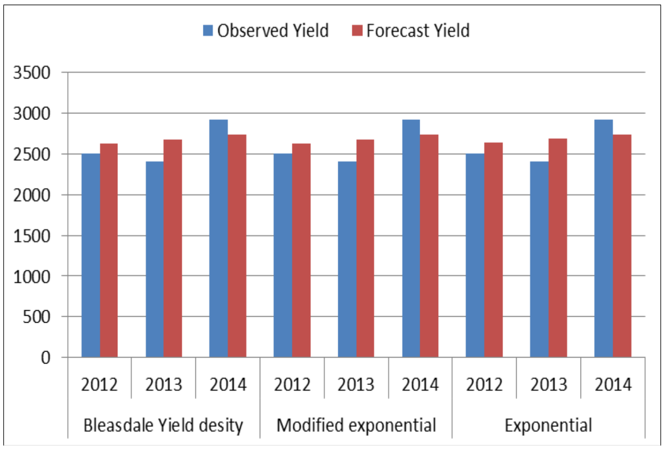
		2012	2013	2014			
		Observed Yield					
		2499.00	2405.00	2920.00			
Model Name	**R^2**	**Forecast Yield**			**% Dev**	**RMSE**	**MAPE**
Linear	0.682	2584.59	2623.82	2663.05	-3.424	201.018	7.107
ARIMA(1,1,0)	0.569	2570.30	2567.96	2568.99	-2.852	227.187	7.216
Rational	0.693	2483.58	2505.04	2525.77	0.618	234.989	6.093
Logistic Power	0.686	2536.69	2568.51	2599.62	-1.507	208.804	6.426
Heat Capacity	0.690	2545.56	2576.47	2606.82	-1.862	207.886	6.572
Ratkowsky	0.688	2552.27	2583.79	2614.59	-2.131	206.619	6.675
Natural Logarithm (Exp)	0.688	2577.99	2616.94	2655.88	-3.160	200.763	7.006
Modified Power	0.682	2586.12	2636.01	2686.86	-3.485	196.050	7.025
Reciprocal Quadratic YD	0.682	2592.93	2631.66	2669.64	-3.758	202.379	7.252
Richards	0.685	2607.26	2651.95	2697.02	-4.331	202.007	7.412
MMF Sigmoidal	0.688	2606.62	2645.52	2684.40	-4.305	204.070	7.458
Bleasdale Yield Desity	0.682	2626.45	2677.02	2728.55	-5.099	205.658	7.655
Modified Exponential	0.682	2628.26	2678.30	2729.24	-5.171	206.385	7.689
Exponential	0.682	2630.72	2681.49	2733.24	-5.270	207.098	7.721
Exponential Decline	0.682	2630.90	2681.67	2733.42	-5.277	207.162	7.724
Hyperbolic Decline	0.682	2631.33	2682.36	2734.40	-5.294	207.268	7.728
Bleasdale Yield Spacing	0.682	2631.75	2682.62	2734.47	-5.311	207.449	7.736
Firajdaghi Harris YD	0.675	2664.39	2728.75	2796.26	-6.617	221.711	8.105
Modified Geometric	0.682	2633.42	2633.42	2633.42	-5.378	225.363	8.230
Saturation Growth Rate	0.675	2679.79	2746.67	2816.91	-7.233	230.971	8.324
Reciprocal YD	0.675	2680.05	2746.95	2817.20	-7.244	231.132	8.328
Reciprocal Logarithm	0.675	2681.88	2749.30	2820.16	-7.317	232.339	8.351
Reciprocal	0.674	2682.70	2750.60	2822.03	-7.350	232.933	8.358
Harmonic Decline	0.674	2683.32	2751.25	2822.71	-7.374	233.321	8.368
Sinusoidal	0.690	2191.94	2228.83	2265.16	12.288	429.790	14.013
Steinhart Hart Equation	0.653	2084.92	2078.74	2069.11	16.571	577.912	19.759
Gaussian	0.686	4126.98	4071.25	4017.90	-65.144	1486.834	57.342

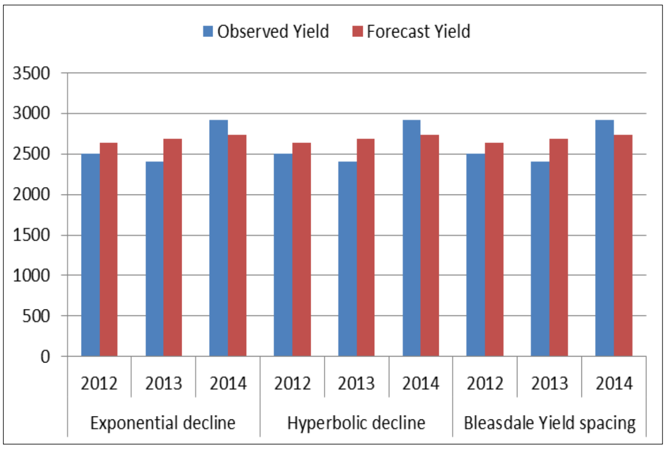

Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014
Linear
ARIMA(1,1,0)

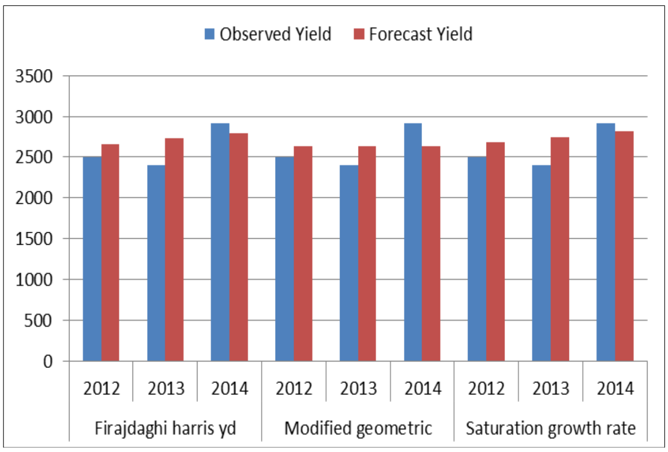

Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Rational
Logistic power
Heat capacity

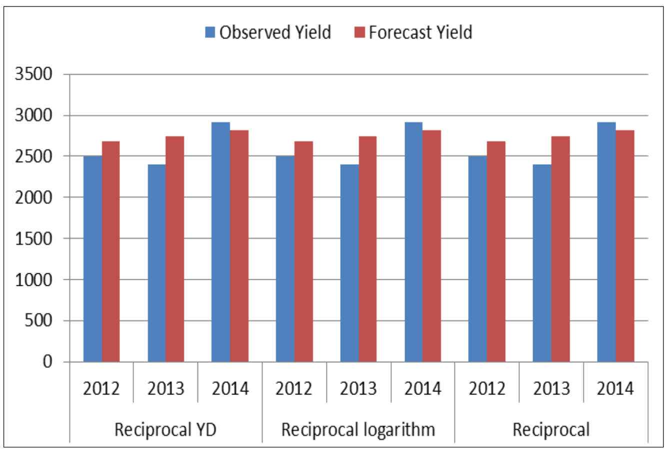

Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Ratkowsky
Natural logarithm (exp)
Modified power


Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Reciprocal quadratic YD
Richards
MMF sigmoidal


Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Bleasdale Yield desity
Modified exponential
Exponential


Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Exponential decline
Hyperbolic decline
Bleasdale Yield spacing


Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Firajdaghi harris yd
Modified geometric
Saturation growth rate


Observed Yield
Forecast Yield
3500
3000
2500
2000
1500
1000
500
0
2012 2013 2014 2012 2013 2014 2012 2013 2014
Reciprocal YD
Reciprocal logarithm
Reciprocal

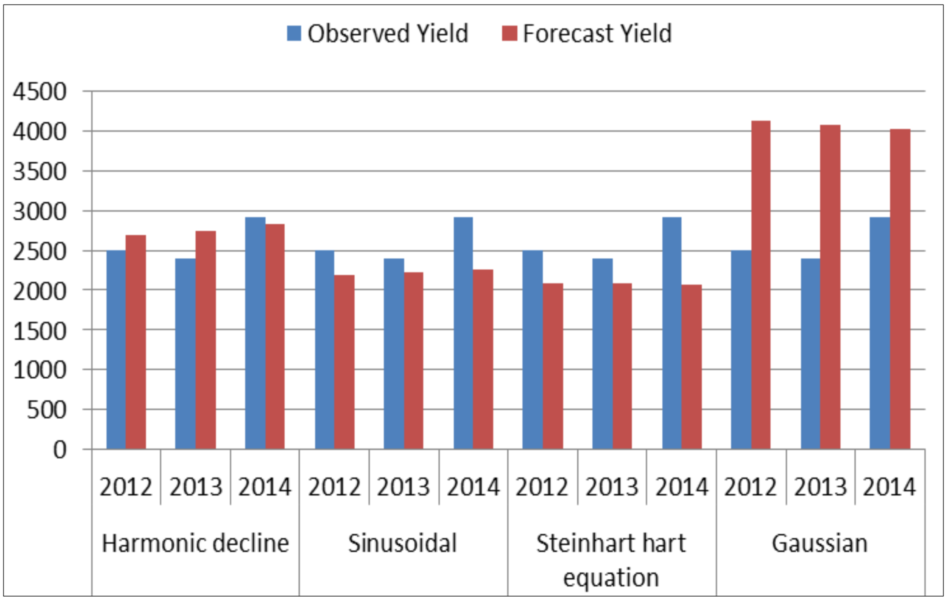


Fig 2: Observed yield forecast yield of rice using different models

Conclusion

The implications of this research are significant for agriculture and decision-making in the Navsari district. The mathematical models play an important role in agricultural research. In this investigation, various nonlinear growth models *viz*., rational, logistic, Richards, MMF etc. were studied. The study indicated that linear and nonlinear models play significant role in rice yield forecast. The good fit of the model indicated change of trend in rice yield which helps formulating price and market availability. The study results in considerable difficulties in the estimation of parameters. By employing a nonlinear approach, stakeholders can make more informed and precise predictions about rice crop yields, enabling better resource allocation and management. Moreover, the methodology can be extended to other crop forecasting scenarios, highlighting its potential as a versatile tool for improving agricultural productivity and ensuring food security in diverse regions.

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