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Trend analysis and test of randomness in soybean cultivation: A case study of Madhya Pradesh and India

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Abstract

This study analyses the trends and randomness in soybean area, production, and yield over a 54-year period for Madhya Pradesh and India. The Test of Randomness was applied to examine whether the data followed a random pattern or exhibited systematic behaviour. Results revealed that all parameters: area, production and yield showed significant deviations from randomness, with t-values less than the critical value at the 5% significance level. This indicates the presence of structured trends in all series. Trend analysis using cubic models further confirmed non-linear patterns in the data. In both Madhya Pradesh and India, area and production exhibited strong model fits with high R^2 values, while yield trends were weaker and more unstable. These findings suggest that while soybean cultivation has expanded steadily in terms of area and production, yield remains inconsistent, especially in Madhya Pradesh. The study highlights the need for targeted interventions to enhance productivity and stabilize yield trends for sustainable soybean growth.

Keywords: Trend, test of randomness, soybean growth, systematic behaviour

Introduction

The soybean (*Glycine max*, family: Leguminosae) is sometimes called the "Golden Bean" of the 20th century because it is a nutrient-dense, high-protein food (Dupare, 2023) ^[5]. Since it contains about 40% high-quality protein that contains all of the essential amino acids, especially glycine, tryptophan, and lysine, it is comparable to cow's milk and other animal proteins. Soybeans are also high in lecithin, vitamin A, and vitamin D, and contain about 20% oil (Dupare *et al.*, 2024) ^[6]. Their nutritional worth is further increased by the approximately 4% mineral salts they contain, which offer healthy levels of calcium and phosphorus. Despite being categorized as a legume, soybeans are mostly grown as oilseeds because of their high oil content and rising demand worldwide (Berk, 1992) ^[2]. However, it's not commonly consumed like other pulses because of the presence of a natural trypsin inhibitor, which affects protein absorption and digestibility. Soybean's adaptability to diverse agro climatic conditions has made it a major commercial crop worldwide. Countries like China, Japan, Indonesia, the Philippines, and many in Europe now import soybeans extensively for both animal feed and human consumption. (Farkade, 2008) ^[3].

Despite being indigenous to China (Qiu and Chang, 2010), soybeans are today grown mostly in Brazil, the United States, Argentina, China, and India, which together produce more than 87% of the world's supply. From less than 30 million hectares in 1970 to around 140 million hectares by 2022–2023, the world's soybean production increased dramatically from 43 million tonnes to almost 395 million tonnes during that time (FAO, 2023) ^[7]. Soybeans, which rank fourth in terms of area and fifth in terms of production worldwide, have become a popular oilseed crop in India. Production rose from 0.014 million tonnes to 14.9 million tonnes, while the area under cultivation expanded from a mere 0.03 million hectares in 1970 to 13 million hectares in 2023. Additionally, during time, yield levels have improved, increasing from 438 kg/ha to 1145 kg/ha.

With more than 50% of the nation's soybean production, Madhya Pradesh is the largest producer in India. From merely 8,000 hectares and 8,000 tonnes in 1970 to 6.06 million hectares and 5.47 million tonnes in 2023, the state's area and production have grown significantly, underscoring its vital position in the nation's soybean economy (FAO, 2023) [7].

The rapidly increasing global population, particularly in developing nations, poses a significant challenge to ensuring adequate food supply. Addressing this issue requires strategic planning at both national and international levels. To make informed decisions, policymakers must understand projected population growth and its implications for future food demand. As a result, forecasting the production trends of major crops becomes critical for achieving food and nutritional security. In this context, having reliable projections for key agricultural commodities is essential for effective planning. Since crop production is influenced by a wide range of factors—including weather conditions, irrigation availability, fertilizer usage, pest and disease management, market dynamics, and the efficiency of farm management comprehensive research that considers these variables is necessary. Such studies not only enhance our understanding of current agricultural patterns but also play a vital role in improving the accuracy of future production forecasts. (Mishra, 2018) [4].

Hence, the present study has been undertaken with the objective of assessing the trends in area, production, and productivity of soybean in Madhya Pradesh and India. Additionally, the study aims to evaluate the stability of these parameters over time and to apply tests of randomness to examine whether the variations in the data are due to systematic patterns or random fluctuations.

Methodology

The present study is based on secondary data. Information on the area, production and yield of Soybean in India and Madhya Pradesh was obtained from the India stat (<https://www.indiastat.com>) database.

Trend Models

Trend model is a structured representation that is used to explain how a system or process behaves. Models are used in statistical analysis to determine a process's fundamental structure as well as the statistical characteristics and ramifications that go along with it. The goal of the current study is to use a variety of statistical models to comprehend the behavior and pattern of the time series being studied. Because of their well-established theoretical features and interpretability, parametric models are frequently chosen among the three main groups of models (parametric, non-parametric, and semi-parametric). Accordingly, this study explores a range of parametric models to analyse the series, as outlined in the following section.

Linear Model: The equation of linear model is given by

$$Y_t = b_0 + (b_1 \times t)$$

Quadratic Model: The equation of Quadratic Model is given by

$$Y_t = b_0 + (b_1 \times t) + (b_2 \times t^2)$$

The Quadratic Model can be used to model a series which “takes off” or a series which dampens.

Compound Model: The equation of Compound Model is given by

$$Y_t = b_0 \times b_1^t \text{ Or } \ln(Y_t) = \ln(b_0) + t \ln(b_1)$$

Cubic Model: The equation of Cubic Model is given by

$$Y_t = b_0 + (b_1 \times t) + (b_2 \times t^2) + (b_3 \times t^3)$$

Exponential Model: The equation of Exponential Model is given by

$$Y_t = b_0 \times e^{(b_1 \times t)} \text{ Or } \ln(Y_t) = \ln(b_0) + (b_1 \times t)$$

Logarithmic Model: The equation of Logarithmic Model is given by

$$Y_t = b_0 + b_1 \ln(t)$$

Growth Model: The equation of Growth Model is given by

$$\ln(Y_t) = b_0 + (b_1 \times t)$$

Where Y_t is value of the series in time t and b_0, b_1, b_2, b_3 are the parameters.

Randomness Test

To test the randomness of a time series, a non-parametric test based on turning points was used. A turning point occurs when a value is either higher (peak) or lower (trough) than its immediate neighbours. At least three consecutive data points are needed to identify a turning point. Among the six possible arrangements of three values, four result in a turning point, giving a probability of 2/3 for each such set (Kendall and Stuart, 1977) [1].

Let a sequence be $\mu_1, \mu_2, \dots, \mu_n$ and define a marker variable X_i to count turning points. The total number of turning points, p , is derived from this. As the sample size n increases, the distribution of p approaches normality. The null hypothesis H_0 (that the series is random) is tested using the standardized test statistic:

$$\tau = \frac{p - E(p)}{S_p} \sim N(0,1)$$

Where, $E(p)$ and S_p are the expected value and standard deviation of p , respectively.

Results and Discussion

Test of randomness for area, production and yield of soybean in Madhya Pradesh and India

To determine whether the time series data of soybean area, production, and yield follow a random pattern or exhibit a systematic trend, the Test of Randomness was applied to the data for both Madhya Pradesh and India, covering 54 years of observations. Table 3 shows the number of observed turning points (peaks and troughs), expected turning points under randomness, and the computed t -statistics for each parameter. The expected number of turning points ($E(P)$) was 34, with a variance ($V(P)$) of 9.28. The test statistic, t_{cal} , was calculated to assess the significance of deviation from randomness. In all cases (area, production and yield for both Madhya Pradesh and India), the computed t_{cal} values were less than -1.96, which is the critical value at the 5% level of significance. This indicates that the null hypothesis of randomness is rejected for

all series. Therefore, all three parameters area, production and productivity exhibit statistically significant trends over time

for both Madhya Pradesh and India.

Table 1: Test of randomness for area, production and productivity of Madhya Pradesh and India

Test of Randomness	Madhya Pradesh			India		
	Area	Production	Yield	Area	Production	Yield
No. of Observation	54	54	54	54	54	54
No. of Turning Point (p)	16	19	22	16	18	19
E (P)	34.00	34.00	34.00	34.00	34.00	34.00
V(P)	9.28	9.28	9.28	9.28	9.28	9.28
t_{cal}	-5.9095	-4.9246	-3.9397	-5.9095	-5.2529	-4.9246
Inference	Trend	Trend	Trend	Trend	Trend	Trend

Trend Analysis of Soybean

A parametric trend analysis was performed to understand the general growth of soybean production and cultivation over time. This required fitting a number of trend models to the area, production, and yield data, including linear, logarithmic,

quadratic, cubic, compound and exponential and growth models. The model with the highest R^2 value, statistical significance, and coefficients was determined to be the best fit for each parameter.

Table 2: Trend in area, production and productivity of Soybean in Madhya Pradesh

Madhya Pradesh						
Equation	Model Summary		Parameter Estimates			
	R Square	Significance	Constant (b)	b_1	b_2	b_3
Area '000 ha						
Cubic	0.969	0.000	-222.505	-3.620	8.188	-0.113
Production '000 tons.						
Cubic	0.901	0.000	262.501	-134.293	14.410	-0.192
Yield (kg/ha)						
Cubic	0.227	0.000	1098.285	-46.107	2.159	-0.026

The non-linear patterns were clearly observed in Madhya Pradesh (Figure 1, 2 and 3). The trend analysis revealed that a cubic model best captured the behaviour of area, production, and yield of soybean over the years. This indicates that the trends have not followed a simple linear or quadratic path but have undergone phases of increase, stagnation, and potential decline. From Figure 1, it can be seen that the area under soybean cultivation in Madhya Pradesh initially increased and then exhibited signs of slight decline in recent years. The cubic model for area had a high R^2 value of 0.969, indicating an excellent fit and strong explanatory power of the model.

The alternating signs of the coefficients further confirm a complex, curved trend in the area under cultivation. Similarly, Figure 2 shows the trend in soybean production, which also followed a cubic pattern with an R^2 value of 0.901, suggesting high accuracy. Initially, production grew, likely due to increased area and better inputs, but later showed signs of fluctuation, possibly due to climatic or market factors. However, the pattern for yield in Figure 3 was notably different. The cubic model fit yielded an R^2 value of only 0.227, indicating a weak fit. This suggests that soybean productivity in Madhya Pradesh has been unstable.

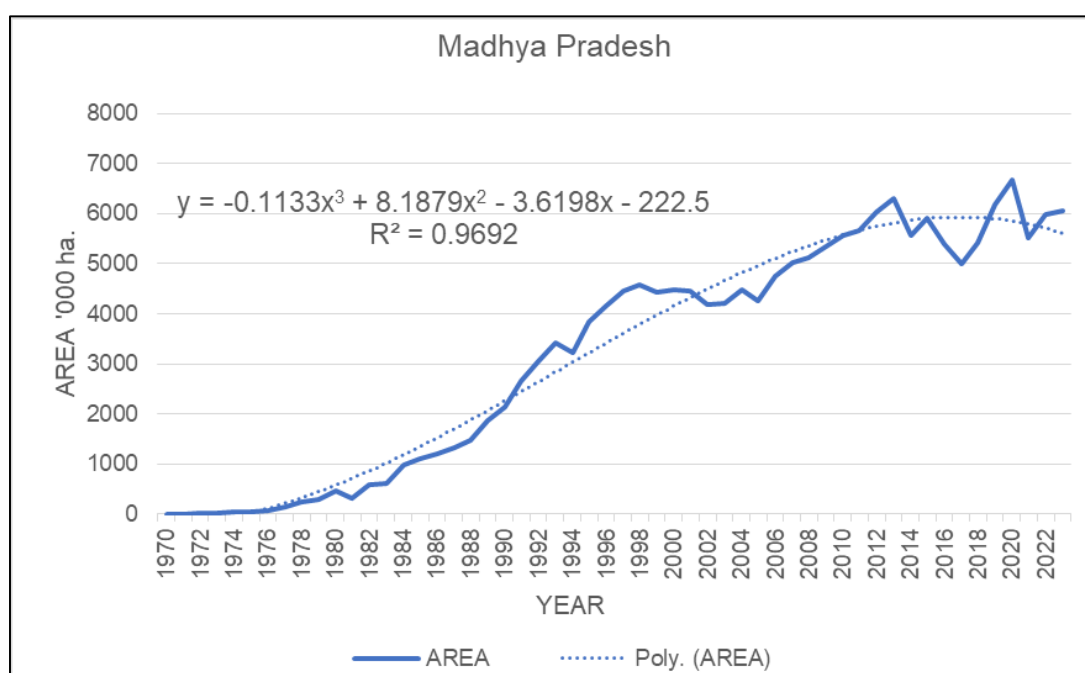
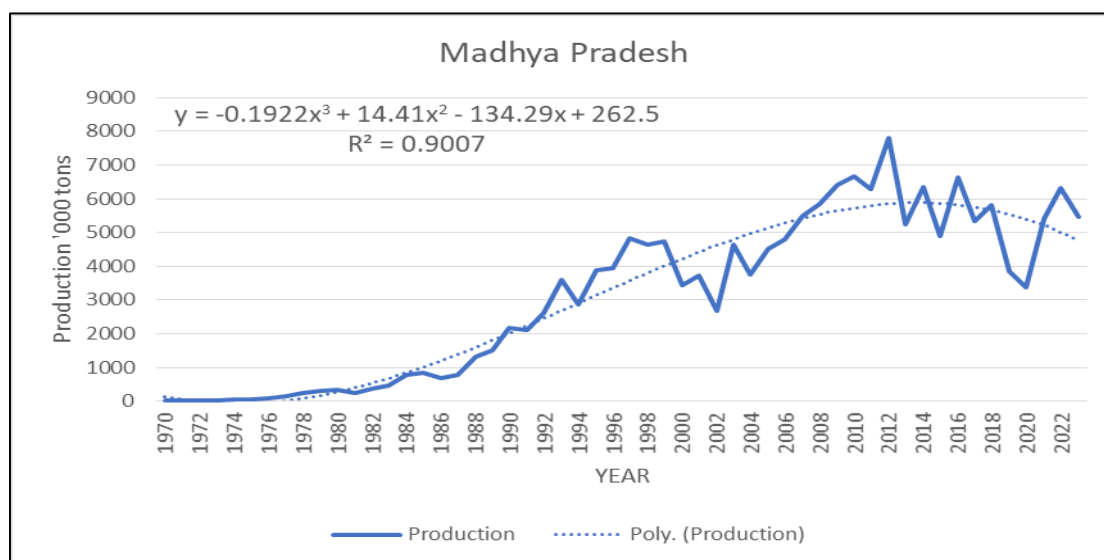
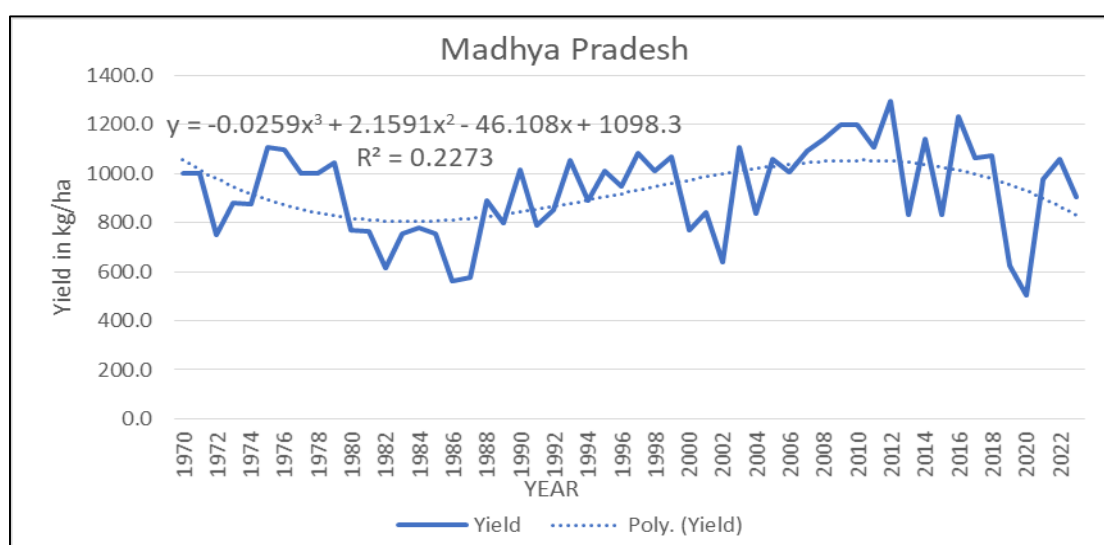


Fig 1: Observed and expected trend of area under Soybean in Madhya Pradesh

**Fig 2:** Observed and expected trend of Soybean production in Madhya Pradesh**Fig 3:** Observed and expected trend of Soybean yield in Madhya Pradesh**Table 2:** Trend in area, production and productivity of Soybean in India

India						
Equation	Model Summary		Parameter Estimates			
	R Square	Significance	Constant (b)	b_1	b_2	b_3
Area '000 ha						
Cubic	0.990	0.000	308.942	-146.713	16.599	-0.180
Production '000 tons.						
Cubic	0.949	0.000	737.725	-273.556	22.524	-0.244
Yield (kg/ha)						
Cubic	0.463	0.000	700.000	-0.063	0.598	-0.009

The non-linear patterns were clearly observed at the national level in India (Figures 4, 5, and 6). The trend analysis indicated that acubic model provided the best fit for the area, production and yield of soybean over time, capturing the complex nature of the trends. These patterns suggest that soybean cultivation in India has undergone significant changes. From Figure 4, it is evident that the area under soybean cultivation in India increased substantially during the early years, reflecting expansion into new regions and adoption by more farmers. However, the trend later showed signs of slight decline. The cubic model for area recorded an R^2 value of 0.990, demonstrating reliability of the model. The shifting signs of the coefficients further confirm the curved and non-linear trajectory of soybean acreage in India. Figure 5

illustrates the trend in soybean production, which also followed a cubic pattern with a high R^2 value of 0.949, indicating a very good model fit. Initially, production increased with area expansion and technological improvements. However, the later part of the trend revealed fluctuations, possibly due to external factors. In contrast, the trend in yield (Figure 6) displayed a more moderate fit. The cubic model for yield had an R^2 value of 0.463, indicating a weaker but still meaningful trend. This suggests that soybean productivity in India has shown some improvement, but the variability remains substantial. The low magnitude of the coefficients also points to a relatively flat curve, implying that yield growth has been slow and unstable compared to area and production.

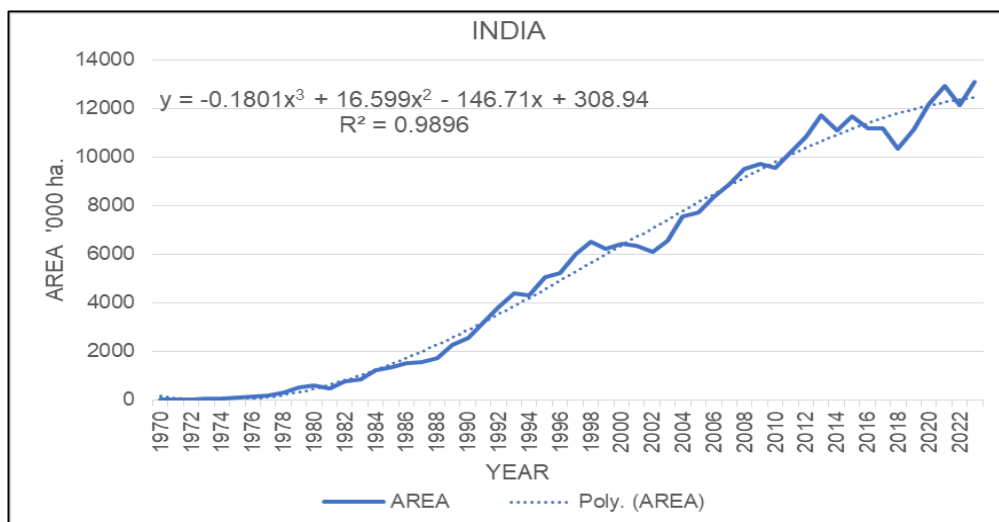


Fig 4: Observed and expected trend of area under Soybean in India

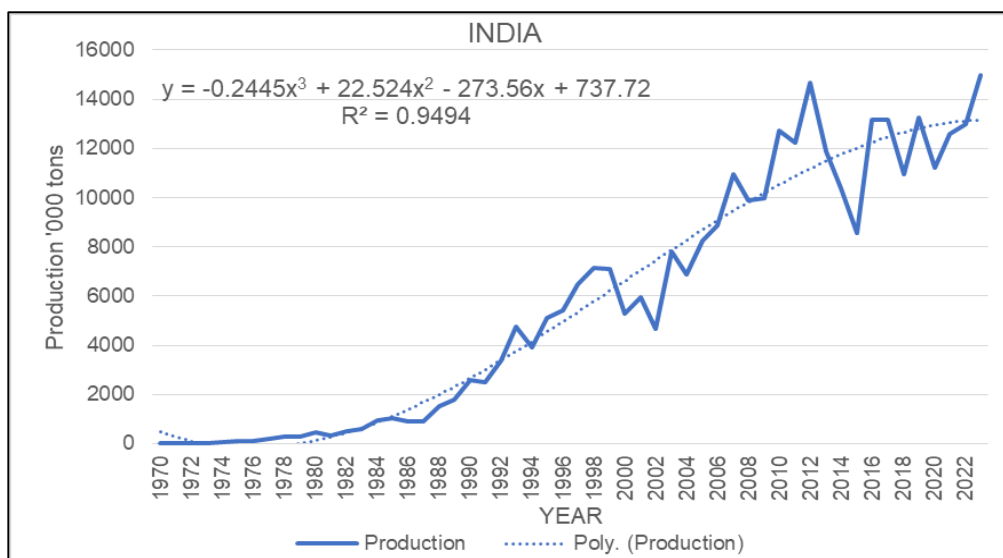


Fig 5: Observed and expected trend of Soybean production in India

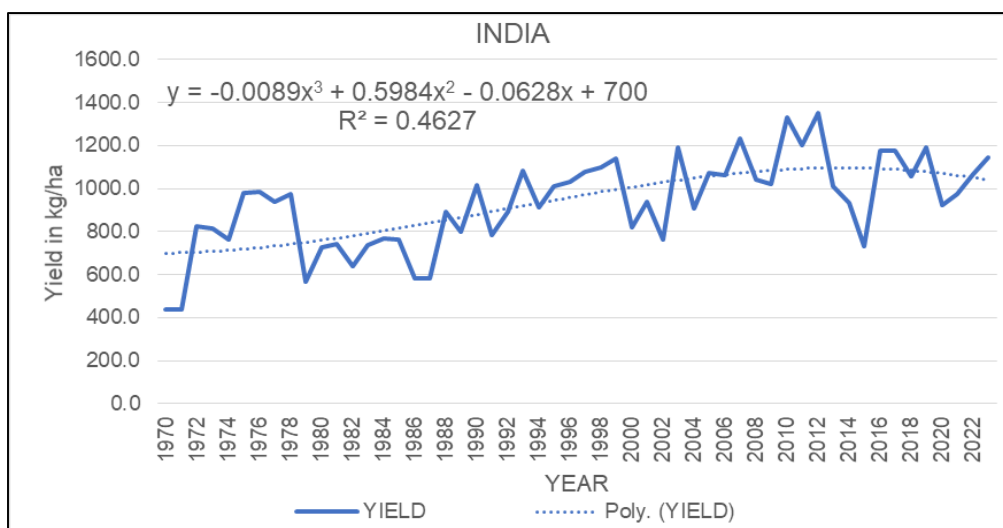


Fig 6: Observed and expected trend of Soybean yield in India

Conclusion

The Test of Randomness and trend analysis of soybean area, production, and yield over 54 years for Madhya Pradesh and India revealed significant, non-random patterns. All computed t-values were below the critical limit of -1.96, leading to the rejection of the null hypothesis and confirming the presence

of systematic trends. Cubic models provided the best fit, capturing the non-linear behaviour of the data. In Madhya Pradesh, area and production trends showed strong fits ($R^2=0.969$ and 0.901), indicating consistent growth over time. However, yield trends were unstable, with a low R^2 value of 0.227 . Similarly, at the national level, India's area and

production trends had very high R^2 values (0.990 and 0.949), while the yield trend had a moderate fit ($R^2=0.463$). These results indicate that although soybean cultivation has expanded, yield remains variable. Targeted interventions are needed to improve productivity and ensure sustainable soybean development.

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