A STUDY ON TREND, GROWTH AND STABILITY OF PULSE PRODUCTION IN MIRZAPUR DISTRICT OF UTTAR PRADESH, INDIA

Thesis
Submitted to the

Acharya Narendra Deva University of Agriculture & Technology,
Kumarganj, Ayodhya - 224229, Uttar Pradesh, India

By
Ashutosh Dubey
I.D. No. A-14717/23

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Master of Science (Agriculture)

IN

AGRICULTURAL STATISTICS

July, 2025

CERTIFICATE-I

This is to certify that the thesis entitled **"A Study on trend, growth and stability of pulse production in Mirzapur District of Uttar Pradesh, India"** submitted in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)** with major in **Agricultural Statistics** of the College of **Agriculture** Post Graduate Studies, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya is a record of *bonafide* research carried out by **Mr. Ashutosh Dubey, Id. No. A-14717/23**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Kumarganj, Ayodhya

15 July, 2025

(Piyush Kumar Singh)

Chairman

Advisory Committee

CERTIFICATE-II

We, the undersigned, member of Advisory Committee of **Mr. Ashutosh Dubey**, Id. No. **A-14717/23** a candidate for the degree of **'Master of Science (Agriculture)'** with major in **Agricultural Statistics** agree that the thesis entitled **"A Study on trend, growth and stability of pulse production in Mirzapur District of Uttar Pradesh, India"** may be submitted in partial fulfillment of the requirements for the degree.

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CERTIFICATE-III

DECLARATION FOR ANTI-PLAGIARISM

I, **Ashutosh Dubey**, Id. No. **A-14717/23**, certify that the thesis entitled **"A Study on trend, growth and stability of pulse production in Mirzapur District of Uttar Pradesh, India"** submitted in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)** in **Agricultural Statistics** to the College of Agriculture, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) is original work and has similarities with published work not more than minor similarities as per the UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations, 2018, adopted by the university.

I declare that I have faithfully acknowledged, given credit to and referred to the research workers wherever their works have been cited in the text and body of the thesis. I further certify that I have not wilfully lifted up some others' work, para, text, data, results, etc. reported in the journals, books, magazines, reports, dissertations, thesis, etc., or available at web-sites and included them in this thesis and cited as my own work.

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(Signature of the candidate)

Place: Kumarganj, Ayodhya

Date: 15 July, 2025

CERTIFICATE FROM THE MAJOR ADVISOR

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Major Advisor)

9/7/25

Head of the Department

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Date: 15/07/2025

आशुतोष दूबे

Place: Kumarganj, Ayodhya

(Ashutosh Dubey)

TABLE OF CONTENTS

(a) LIST OF TABLES

(b) LIST OF FIGURES

(c) ABBREVIATIONS

%	:	Per cent
&	:	and
/	:	Per
qt/ha	:	Quintals per hectare
e.g.	:	(exempli gratia) for example
et al.	:	et alia (and associates)
i.e.	:	(Ed est.) that is
viz.	:	(Videlicet) namely
3MA	:	3-Year Moving Average
5MA	:	5-Year Moving Average
LGR	:	Linear growth rate
CGR	:	Compound Growth Rate
CDVI	:	Cuddy Della Valle Index
Fig.	:	Figure
I	:	Instability Index
CV	:	Coefficient of variation
SD	:	Standard Deviation
DES	:	Directorate of Economics and Statistics
DAC&FW	:	Department of Agriculture, Cooperation & Farmers Welfare
FPO	:	Farmer Producer Organization
ICAR	:	Indian Council of Agricultural Research
NFSM	:	National Food Security Mission
TMOP	:	Technology Mission on Pulses
RSI	:	Relative Spread Index
RYI	:	Relative Yield Index
KVK	:	Krishi Vigyan Kendra
FAO	:	Food and Agriculture Organizations
MAPE	:	Mean Absolute Percentage Error
RMSE	:	Root Mean Squared Error
Adj. R^2	:	Adjusted r-squared
R^2	:	Coefficient of Determination
MSP	:	Minimum Support Price
ARIMA	:	Autoregressive Integrated Moving Average
VAR	:	Vector Autoregression

Chapter 1

INTRODUCTION

1.1 Mirzapur District Profile

Mirzapur is positioned at 25.15°N latitude and 82.58°E longitude, with an average elevation of about 80 meters (265 feet) above at sea level. Geographically, it lies between 23.52°–25.32° North latitude and 82.7°–83.33° East longitude, forming a part of Varanasi district. It is bounded by Varanasi district to the north and northeast, Sonbhadra district to the south and Prayagraj district to the northwest. While most of its northern and western boundaries are marked, a 13-kilometer stretch in the northeast is defined by the Ganga River, which separates Chunar Tehsil from Varanasi district. This district is famous for the Vindhyavasini temple. Mirzapur also carries historical importance, as the Mirzapur Clock Tower is the reference point for Indian Standard Time (IST), calculated using the 82.5° E longitude that passes through the city. (Source: *District Mirzapur, Uttar Pradesh Website and Ministry of MSME, Govt. of India*)

Mirzapur district, covering 4521 km² with a population of over 2 million, is split into four subdivisions, 12 blocks and 1698 villages. It has important agro-ecological regions: the fertile Gangetic plain (30-40%) and the degraded Vindhyan region (60-70%). The Gangetic Plain is well-irrigated with fertile alluvial soil, which is best for rice-wheat farming, whilst the Vindhyan location faces water shortage and land degradation, with 40% of land cultivable and no assured irrigation. Semi-arid weather gets 1100 mm of rainfall annually, in general during the monsoon season, with unreliable post-rain and wintry weather showers. The district faces ecologically demanding situations because of rolling topography, industrialization, non-medical agriculture, deforestation and soil degradation, main to low soil productivity and erratic rainfall patterns. (Source: *KVK, Mirzapur, U.P.*)

The Mirzapur District in Uttar Pradesh, located in the South-East part of the state, is characterized by its mixed agricultural system, where pulse crops have traditionally played a key role. However, like many other districts in India, Mirzapur has experienced variability in pulse production over the years, influenced by both environmental and socio-economic factors. Understanding the trends, growth patterns, and stability of pulse production in this district is essential for formulating policies supporting sustainable farming practices, ensuring food security and improving farm incomes.

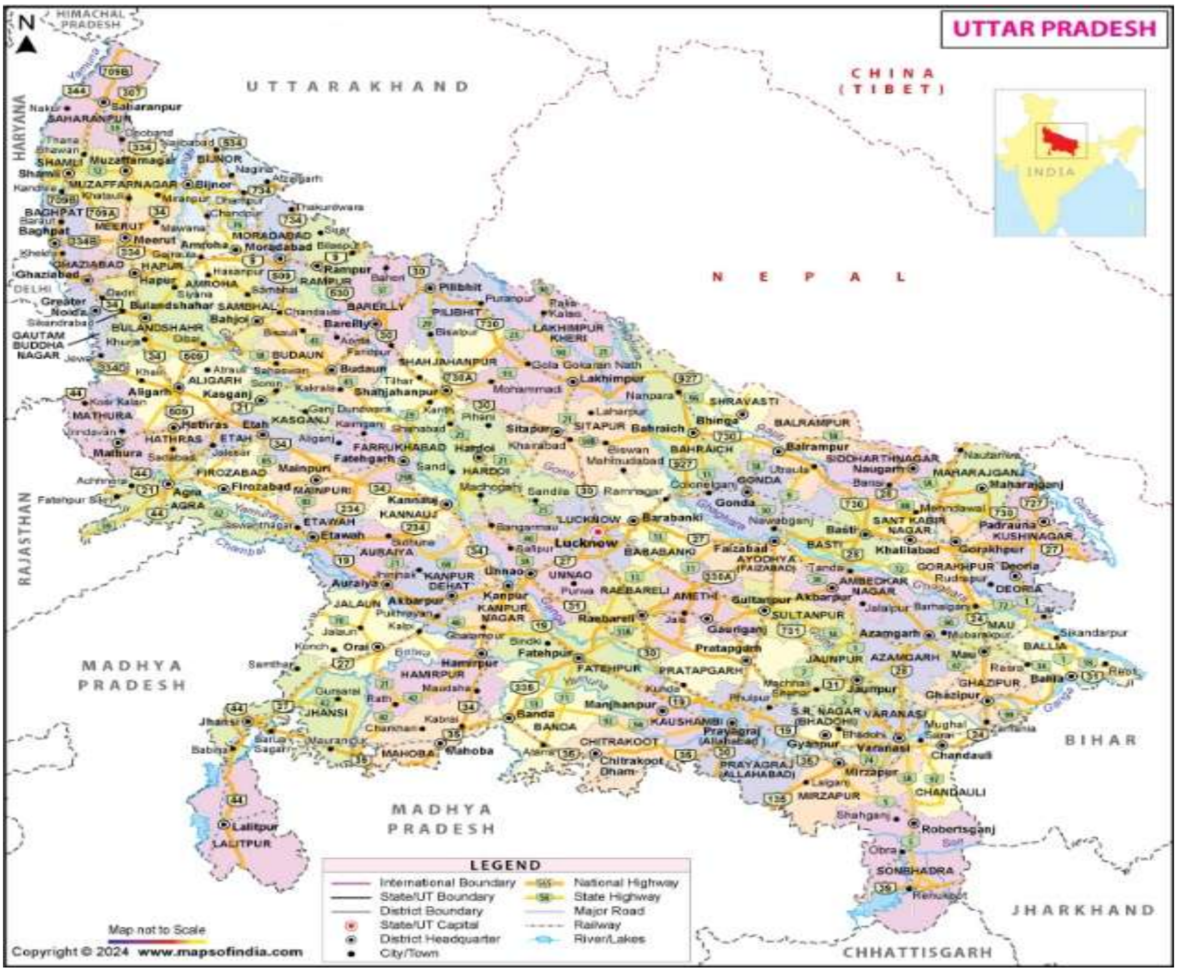

Fig. 1.1 Map of Uttar Pradesh, India

(Source: *https://www.mapsofindia.com/uttar-pradesh/*)

Fig. 1.2 Map of Mirzapur District, Uttar Pradesh

(Source: *https://www.mapsofindia.com/maps/uttarpradesh/districts/mirzapur.htm*)

1.2 About Pulse Crops

Agriculture is the backbone of the Indian economy, with pulse crops vital in ensuring food security, improving soil health and providing a rich source of plant-based proteins. Pulses, which include crops such as lentils, chickpeas, peas and various types of beans, are an integral part of India's agricultural landscape due to their adaptability to diverse agro-climatic conditions, low input requirements and their ability to fix nitrogen in the soil, thereby enhancing soil fertility. Despite these advantages, the production of pulses in India has been marked by notable fluctuations, often driven by changes in rainfall patterns, market volatility and agricultural policies. This instability presents a significant challenge to ensuring the consistent availability of these essential crops, particularly in regions like Uttar Pradesh, where pulses are a staple part of the diet and contribute to the livelihoods of millions of farmers. Union Finance Minister Nirmala Sitharaman announced a new six-year "Mission for Aatmanirbharta in Pulses" in the Union budget 2025-26 to boost the output and help achieve self-sufficiency in pulses, with a special focus on three key widely consumed varieties (Tur, Urad, and Masoor). (Source: *Ministry of Agriculture & Farmers Welfare, India*)

Arhar (***Cajanus cajan*** **L.)**, known as Pigeon pea, thrives in Mirzapur's semi-arid climate and well-drained loamy soils, making it an important crop for rainfed farming. Besides its agricultural significance, arhar is valued for its high protein content and its ability to improve soil fertility through nitrogen fixation. These benefits make it essential for both the local economy and nutritional security. In 2021-22, arhar was cultivated over 15,987 hectares in Mirzapur, yielding a total production of 160,030 quintals, with an average productivity of 10.01 quintals/hectare. (Source: *DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India, 2021-22*)

Gram (*Cicer arietinum* L.), generally referred to as chickpea, is one of the key pulse crops grown in Mirzapur because it contains high nutritional value and helps in sustainable agriculture. Gram is rich in protein, dietary fiber and vital minerals and is a crucial component of the Indian diet. In addition to being nutritious, gram improves soil fertility through nitrogen fixation in the air and hence promotes better yields of the succeeding crops. The crop also thrives in semi-arid conditions with moderate rainfall and well-drained soils and hence makes it a necessary part of crop rotation methods. During the 2021–22 rabi crop season, Mirzapur produced 1,76,680 quintals of gram from 13,868 hectares with an average yield of 12.74 quintals/hectare. (Source: *DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India, 2021-22*)

Lentil (*Lens culinaris* L.), or masoor, is a significant pulse crop grown in Mirzapur because of its nutritional importance and the role it plays in sustainable agriculture. Lentils contain protein, dietary fiber, iron, folate and an important constituent of Indian cuisine, particularly in the diet of vegetarians. Lentil also enhances soil fertility by nitrogen fixation of atmospheric nitrogen and hence supports sustainable cropping systems. The crop is ideally adapted to semi-arid environments with moderate rainfall and thrives on loamy soil with adequate drainage, often as a component of crop rotation to increase productivity and soil health. In the 2021-22 crop season, lentil cultivation in Mirzapur was 50690 quintals, sown in 5570 hectares, at an average of 9.10 quintals/hectare. (Source: *DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India, 2021-22*)

Urad (*Vigna mungo* L.), known as Uradbean, locally referred to as black gram, is an important pulse crop cultivated in Mirzapur and is prized for its nutritional value as well as use in sustainable agriculture. It is rich in protein, dietary fiber, iron and other trace micronutrients and therefore comes into significant application in Indian cooking. It is also an agent of soil health since it possesses the ability to fix atmospheric nitrogen, thus improving the fertility of the soil for the next crop. It grows best in semi-arid conditions with medium rainfalls and loves well-drained loamy soils, which are frequently applied in crop rotation to enhance agricultural sustainability. In the crop year 2021-22, Mirzapur urdbean was produced at 5290 quintals, on 725 hectares of land, having a mean yield of 7.30 quintals/hectare. (Source: *DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India, 2021-22*)

Pea (*Pisum sativum* L.), or matar as it is locally referred to, is one of the major pulse crops being cultivated in Mirzapur because of its higher nutrient content and advantage for sustainable agriculture. It contains high levels of protein, fibre, vitamins and essential minerals and is an edible product widely used in Indian kitchens. Pea farming also tends to improve soil condition through nitrogen fixation, thus making the soil more productive for subsequent cropping. It prefers temperate dry climates with well-drained loam soils and is typically employed within crop rotation systems to improve the overall productivity of a farm. In the 2021-22 crop season, Mirzapur pea production consisted of 39290 quintals, from an area of 3486 hectares and a mean production of 11.27 quintals/hectare. (Source: *DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India, 2021-22*)

This study seeks to fill a gap in the literature by providing a comprehensive analysis of pulse production in the Mirzapur District over nearly three decades (1993-94 to 2021-22). The primary focus of the research is to investigate three key aspects: (1) the trends in pulse production over time, (2) the growth rate of pulse crops in the district and (3) the stability of pulse production, particularly in the face of external shocks such as climate variability, policy changes and market fluctuations. Using time-series data from reliable sources such as the *Sankhikiya Patrika* (Statistical Bulletin) and the Directorate of Economics and Statistics, the study employs statistical models like moving averages, regression analysis and stability indices to assess the performance of pulse production in the district.

The trend analysis aims to uncover whether pulse production has followed a positive, negative, or stagnant trajectory over the years and what factors may have contributed to these patterns. Growth analysis is focused on measuring the rate of increase or decrease in pulse production, providing insights into the district's agricultural productivity and the potential for future expansion. On the other hand, stability analysis looks at the degree of variability in pulse production, seeking to understand how resilient the sector is to external disruptions.

The findings of this research are expected to have significant practical implications. A clear understanding of the trends, growth and stability of pulse production can inform policy decisions aimed at improving agricultural practices, mitigating risks and ensuring sustainable development in the farming sector. Furthermore, the insights gained from this study can help local farmers optimize their production strategies, minimize losses and increase their yields.

In summary, this study on pulse production in Mirzapur District aims to provide a detailed and systematic analysis of the factors influencing production trends, growth and stability. Addressing these issues hopes to contribute to the academic understanding of agricultural dynamics and the practical advancement of pulse farming in the region, offering solutions to the local agrarian community's challenges.

1.3 Objectives of Investigation

1. To demonstrate the production growth rate and trends of pulse crops in the Mirzapur district of Uttar Pradesh.

2. To implement and assess the performance of various statistical models related to pulse crop production.

3. To analyze the statistical coefficients and measures of pulse crop production, including decomposition analysis and validate the selected models.

4. To propose policy recommendations consequent upon the outcomes of the study undertaken.

1.4 Presentation of the Study

The study undertaken is organised in five chapters.

The **first chapter** discusses the Introduction and importance of Pulses. The **second chapter** deals with a brief review of the literature related to the statistical analysis of the area, production and yield of pulse crops. The **third chapter** discusses the materials and procedures employed, as well as the statistical metrics that were used. In **chapter four**, the findings and comments related to the study's aims are provided. In the **fifth chapter**, the study's summary and conclusions are presented.

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Chapter 2

REVIEW OF LITERATURE

Any scientific research must begin with a thorough review of the relevant literature. In addition to providing knowledge about previous work, it also offers insight into the current advancements in the field of research that are being conducted. This chapter presents a comprehensive review of previous studies in the area, which helps identify the research gaps that require more investigation. The pertinent literature related to the objectives of the investigation has been elaborated in the subsequent section.

Gajbhiye *et al.* (2010) evaluated the growth and instability of an important crop, i.e., chickpea, in the Vidarbha region of Maharashtra state. The study was based on secondary data pertaining to the years 1980-81 to 2007-08. The results revealed that the growth rates for area and production of chickpea were significant. Instability studied in chickpea indicated that productivity under chickpea exhibited less variation. It means that production of chickpea over the period has been almost constant.

Ardeshna *et al.* (2011) explored the growth of area, production and yield of arhar, gram and total pulses in different districts of Gujarat. The data were analyzed for the period from 1960–61 to 2007–08. The acreage under arhar significantly increased in Gujarat at the rate of 1.38 per cent per annum during 1960–61 to 2007–08. Similarly, the area under pulses also significantly increased in Gujarat but at a lower rate during 1960-61 to 2007–08. The production of arhar significantly increased at the rate of 5.35 per cent per annum, while the production of pulses significantly increased at the rate of 2.95 per cent per annum in the state during 1960–61 to 2007–08. The compound growth rates of productivity of arhar and gram were negative and that of total pulses were positive but non-significant in Gujarat during 1990–91 to 2007–08.

Sharma *et al.* (2013) examined the growth and trend of pulse production in India using time series data on Area, production, yield, and trade from 1980-81 to 2008-09. The period had been divided into two parts: before (1980-81 to 1994-95) and after (1995-96 to 2008-09). Linear, semi-log and compound growth functions were tried to examine the growth and trend. The compound growth was, however, found to have the best fit with the data. The positive percent change in area, production and yield of pigeon pea, chickpea and total pulse has been observed during both before and after the launch of Technology Mission on Pulses (TMOP), except in case of lentil there was a negative percent change in area of chickpea and the yield of pigeon pea also showed a negative percent change before the launch of TMOP. The pigeon pea showed positive growth in area and production at the rate of 0.50 and 0.20 percent annually, while its yield showed a downtrend with 0.30 percent annually. In chickpea, the positive values of 0.20, 0.50 and 0.30 percent annually in area, production and yield during the post period of TMOP have been found. The area and production of lentil have grown by 1.80 and 2.50 percent annually, respectively, during the entire period of study, while its yield observed a negative growth rate of 0.20 percent during the post-period of TMOP. For total pulse production and yield had risen by 0.50 and 0.70 percent annually, respectively, during the entire period of study, while its area had decreased by 0.20 percent per annum.

Srivastava *et al.* (2013) aimed to determine the compound growth rates of area, production and productivity of major pulses (chickpea and pigeon pea) in eastern Uttar Pradesh. The study observed that the decline in area under chickpea and pigeon pea in eastern Uttar Pradesh is the main reason for the decline in production. There is a need to bring more area under chickpea and pigeon pea cultivation and improve the productivity to increase production.

Sharma *et al.* (2014) analyzed based on the different regions of Uttar Pradesh. Various statistical tools were used to determine the growth rates, instability of variation of area, production and productivity of different pulse crops and total pulse crops for two periods before and after the launch of technological missions on pulse production in the country. The time series data from 1960-61 to 2005-06 have been considered, divided into two periods, before (1960-61 to 1989-90) and after (1990-91 to 2005-06) launch of the Technology Mission on Pulse production. The pulse crops, i.e., arhar, pea, gram and lentil, as well as total pulses, were taken for the study. It had been found that the area of pea of the Bundelkhand region has been more stable in the pre-technology mission. The same trend follows in the case of production. Increases or decreases in area and production of different regions have been carried out over different decades. The overall results indicate that the Bundelkhand region is more stable concerning all the pulse crops considered under study.

Chatterjee *et al.* (2014) evaluated the overall trend in area, production and productivity of pulses as well as their respective growth rates and instability during the period 1986-87 to 2007-08 for the sixteen major pulse-growing states of India. Also, performance scoring of each state for kharif, rabi and total pulses had been obtained to rank the sustainability level of that crop in the periods under study. For determining instability measurement, the weighted coefficient of variation method was followed. Regarding performance indices, composite scoring of economic characters, followed by K-Means and Hierarchical cluster analysis, was obtained. The results envisage the fact that there is a tendency to shrink kharif pulses area (-3.89%) more than the rabi pulses (-2.31%) decadally, with respective growth in productivity (1.49% and 9.47% respectively). Regarding instability in area, production and yield of pulses, although rabi season is more potential for pulse production, instability in rabi pulses across states was more than that of kharif pulses which indicating more scope of refinement of technologies of the rabi pulses compared to kharif for all states and also there is still room for certain areas, for putting to use monocropped kharif areas under double cropping.

Narayan and Kumar (2015) analyzed the status of pulse growth and constraints of technology inadequacy as well as policy reform and also focused on constraints of non-availability of essential inputs i.e., quality seed, life-saving irrigation, fertilizers and nutrients, price policy implications and marketing to be reoriented to bring it in tune with the emerging demand and supply of pulses in India. This study resulted in the growth rate of area -0.09, -0.60 and 1.62 and production 1.52, 0.59 and 3.35 during the 1980s, 1990s and 2000s decades, respectively, which affected the net per capita per day availability of pulses, which has declined sharply from 61 gm to 32 gm from 1950-51 to 2009-10. Therefore, the gap between domestic demand and supply widens sharply.

More *et al.* (2015) compared the performance of pulse crops in Gujarat in high-growth periods and across the earlier periods. Time series data from the year 1960-61 to 2010-11 were used. The performance of the crop was analyzed by decade, i.e., period I to period V and overall period, with the help of statistical techniques like Average, Growth Rate, Cuddy-Della Valle Instability Index and Decomposition Model. Results showed that the pulse area in the state was considerably increased. In recent years, the area under Pigeon pea (*Cajanus cajan*) and other pulses has decreased and chickpea area under chickpea has increased. Pigeon pea and other pulse crops, i.e., green gram (*Vigna radiata*) and black gram (*Vigna mungo*), have recorded phenomenal growth during the years 1969-70 to 1979-80. Chickpea (*Cicer arietinum*) crop performed better during the high growth period of Gujarat, compared to other pulse crops. Period III, i.e., 1980-81 to 1989-90, was found to be an antipulse decade in which the productivity of all the major pluses was hampered. Pigeon pea crop was more stable compared to other pulse crops in the state. Area expansion was a major reason for the increase in production of Pigeon pea and chickpea in the state. The production of green gram and black gram was increased because of an improvement in the yield and its interaction with the area.

Devi *et al.* (2017) analyzed the trend in the production of total pulse crops in India for the period 1950-51 to 2014-15, i.e., the past six decades in India. The compound growth rate of yield over six decades was positive and significant, while area and production were non-significant. The decomposition analysis showed that the increase in production of pulses during the period 1994-95 to 2013-14 was mainly due to the yield effect.

Kalia and Mishra (2017) attempted to estimate the relative impact of various price and non-price factors on the allocation of acreage to different pulse crops by analyzing time series data from 2000-01 to 2011-12. The Nerlovian Supply response model was used in the study. Results revealed that the area under arhar is an important determinant of supply response in Allahabad and Mirzapur districts of Uttar Pradesh. It had a positive impact on the farmer's decision regarding acreage allocation. The area under the crop is increasing, but at a decreasing rate. The lagged yield by one year showed a significant response in both cases, which indicates that it has significance in the acreage allocation.

Bhavya *et al.* (2018) attempted to identify the trends of area, production and productivity of chickpea in Prakasam district of Andhra Pradesh through fitting linear and non-linear growth models. Secondary yearly data on area, production and productivity of Chickpea for a period of 39 years, i.e., from 1975-76 to 2013-14, were used. For forecasting up to 2020 AD, a two-year moving average model was identified as the best model for the area, production and productivity of Chickpea. It was observed that there is a slight increase in area and production, whereas productivity showed stability in growth.

Bisht and Kumar (2018) examined trends in the area, production and yield of major pulses in India through growth rate and instability analysis from 1996-97 to 2015-16, which were further divided into two sub-periods characterizing the period before and after the National Food Security Mission (NFSM). The growth rates were calculated by fitting the exponential growth function and instability was analyzed by generating the Cuddy Della Valle index for the five major pulses of India and the pulses as a whole. The results had shown a highly significant but low growth rate of 2.14 percent in pulses production during this period. The growth rate is significantly higher in sub-period II. The area and yield under pulses had also shown a marginal but significant growth rate of 0.44 and 1.19 percent, respectively. But the yield growth rate was found to be higher than the growth rate in area, implying that area allocation under pulses is increasing poorly even after NFSM, while improvements in yield are there.

Changela and Devi (2018) studied the trend in area, production and productivity of major pulse crops, i.e., chickpea and pigeon pea, grown in Gujarat as well as India. The results showed that the CGRs of area, production and yield over sixteen years (2001-02 to 2016-17) were positive and significant for total pulses in India, while in Gujarat, production and yield were increased significantly. Further, it was observed that the CGR of area, production and yield of chickpea was positive and significant, whereas in the case of pigeon pea, the CGR of production and yield was positive and significant in Gujarat. The decomposition analysis concluded that the increase in area under chickpea, pigeon pea and total pulses played a significant role in boosting their production in India. However, in Gujarat, the increase in yield was the primary factor contributing to the rise in total pulse production.

Devegowda *et al.* (2018) attempted to examine the growth trend in percent for major pulses in India. The overall period was classified into three decades to know decadal growth over the years in area, production, yield and value of output decreased for major pulses. Compound growth rate of 1.27, 2.34, 1.08 and 8.94 for grams, 0.49, 1.13, 0.47 and 7.66 for arhar, 0.21, 0.51, 0.30 and 8.21 for moong, 0.93, 1.19, 0.26 and 8.97 for masoor, 4.90, -4.08, 0.83 and 4.69 for horse gram, 0.03, 0.83, 0.80 and 8.47 for urad, 0.28, 1.41, 1.05 and 8.40 per cent for total pulses in area, production, yield and value of output observed respectively for overall period (1990 to 2015). Decadal growth also followed the same trend for all the pulses. Low productivity, low net return, pulses had been marginalized by highly remunerative competing crops.

Hasan and Khan (2018) analyzed pulse production and consumption patterns in different regions of Uttar Pradesh. The compound growth rate was estimated to study the yield performance of pulses in different regions of the states. The consumption pattern among rural and urban households across different regions was analyzed. It was observed that production of pulses in Uttar Pradesh has decreased from 49 lakh tonnes (1994-95) to

27 lakh tonnes (2008-09) and yield has decreased from 17 q/ha (1994-95) to 10 q/ha (2008-09), respectively. Bundelkhand region was found as dominant in pulse production with about 11 lakh hectares of area and 16.86 lakh tonnes production in the triennium ending 2008-09. The growth rate was also highest in the Bundelkhand region in 2000-09. The share of pulses in the consumption basket was not uniform among the regions and showed inter-regional variations.

Kumar *et al.* (2018) examined the performance and the percentage contribution of area, yield and their interaction on pulse production for each decade and the overall period was also estimated. It has been observed that the growth of area, production and yield for pulses registered a positive trend during the overall period. Decomposition analysis was performed and the percentage contribution of area, yield and their interaction on pulses production for each decade and the overall period was also estimated. The yield effect has the largest contribution in pulses for the overall period. Response to change in production because of the effect in the area is evident during the fifties, sixties and nineties. In the seventies and eighties, the change in production was due to the reduction in the yield effect. The interaction of area and yield is not much except in the nineties.

Sachan *et al.* (2018) studied the regional growth analysis of pulse production in Uttar Pradesh, India. The study revealed that there was positive growth of area, production and productivity of urd bean, pea and moong bean, whereas the rest of the crops showed mixed trends. Variability of pulses was on the higher side for production and productivity. There was a decrease in the production of pulses, though an increase in productivity was noticed due to a reduction in the area under pulse cropping. The future projection showed that there is are lag behind the production of pulse crops as it is decreasing every year, which leads to malnutrition for the majority of the population in the state.

Ray and Bhattacharyya (2020) attempted to examine India's production, productivity and net availability of pulses. Time series parametric models, such as linear, quadratic, exponential and logarithmic models, were developed and tested for stochastic trend estimation in order to determine the best econometric model to capture the trending behaviour of the pulse data series taken into consideration in this study. Time series analysis for forecasting may be regarded as a useful practice to develop an appropriate econometric model for estimating future behavior on the basis of previously observed behavior.

Singh and Bansal (2020) explored the status of pulses in Punjab with the computation of compound annual growth rate (CAGR) and decomposition analysis. For this purpose, secondary data from the years 1985-86 to 2017-18 were taken. The results showed that the CAGR of area and production of total pulses in the state showed a significantly negative growth of 6.13 and 5.60 per cent per annum, respectively, but positive growth (0.61%) was observed in the case of yield. The decomposition analysis concluded that the area effect (99.48%) was the major contributing factor for the change in production of total pulses, followed by the yield effect (3.87%). But the interaction effect was found to be negative (-3.35%).

Sah *et al.* (2021) examined the temporal changes in the area, production and productivity of major pulse crops in the Bundelkhand region of UP during the last two decades (1999-2000 to 2019-20). Consistent decline in overall pulse area (-0.64%) and production (-0.36%) was observed; however, the overall pulse productivity registered a marginal upward trend (0.06%) during the analysis period (1999-2000 to 2019-20). Chickpea (-5.03% and -0.64 %) and lentil (-0.51% and - 4.37%) crops registered the highest decline in overall area and production, respectively. Uradbean registered the highest decline (-6.52%) in productivity during the said period. In contrast, the Mungbean crop, followed by Uradbean, recorded the highest growth in area (3.48%, 3.02%) and production (3.61%, 2.71%), while field pea registered the highest productivity growth (1.96%). Instability of pulse production over the study period was high (30.31%); however, the instability in pulse area was low (11.7%). Analysis of inter-district variation in pulse performance reflected a decline in area and production of pulses in all districts except in Lalitpur.

Pandey *et al*. (2021) investigated the trend of pulses in Eastern Uttar Pradesh, as well as their instability and non-linear model. This time series data on pulses pertains to the period 1980-1981 to 2014-15 and includes information on the area, production and productivity of pulses. Pulses had negative growth in terms of area, production and productivity in all three zones of Eastern Uttar Pradesh, namely, the North Eastern plain zone, the Eastern plain zone and the Vindhyan zone. Since 1980-81, there has been a rise in the area and output of pulses in the Vindhyan zone, as seen by the percentage change. The Eastern plain zone had the most stable pulse crop in terms of instability.

Salunkhe *et al.* (2021) studied the growth and instability of chickpea production in Maharashtra from 1980-81 to 2017-18. The growth rates of area (4.01 %), production (6.59

%) and productivity (2.48 %) were observed to be positive and highly significant at a 1 % level of significance during the overall study period. A similar trend was observed for all regions, viz. Western Maharashtra, Vidarbha, Marathwada and Konkan region for the entire study period. It was revealed that the area, production and productivity of chickpea were inconsistent or instable for the entire period in all the regions of the state except in the Konkan region.

Ansari *et al.* (2022) estimated the growth, instability and decomposition analysis of pulses production in Uttar Pradesh from 1990-91 to 2018-19. The study period was split into three sub-periods (Period I: 1990-91 to 2000-01, Period II: 2000-01 to 2010-11 and Period III: 2010- 11 to 2018-19). The total period analysis revealed that the area and productivity effects were -14.33 per cent and 25.28 per cent, respectively, while the interaction effect was -0.65 per cent. With respect to the sub-period study, area had a positive influence of 2.6 per cent on pulse production during the first sub-period, while productivity also had a positive effect. The area, productivity and interaction effects during the second sub-period of the research were 0.01 per cent, -8.09 per cent and -0.043 per cent, respectively. During the third sub-period, there was a beneficial impact of productivity and interaction on pulse production, whereas the area effect on production was observed to be negative.

Devi and Mehla (2022) attempted to examine trends and growth patterns of major pulse crops in India based on secondary data collected from various published sources for the period 1980-2020. The major pulse crops (Green gram, Black gram and Chickpea) had been taken under consideration and data on area, production and yield of selected crops had been utilized at the India level. Standard deviation (SD) and Coefficient of Variation (CV) were used to measure the variability in the collated data. The compound annual growth rates (CAGR) for area, production and yield were estimated and found to have the best fit with the data. The linear model was fitted to estimate the trends of area, production and yield of the crop. The study revealed that the highest average area in India was under chickpea, followed by black gram and green gram and that production and yield follow the same pattern. In terms of area and production, black gram showed the largest fluctuations, followed by chickpea and green gram. The most stable yield was found in chickpea among all selected crops.

Kumari and Malik (2023) studied the growth and instability of pulse production across central states in India to estimate its instability. The secondary data on the area, production and productivity of pulses were collected for all the major states from 1970-71 to 2020-21. Statistical tools like compound growth rate for calculating annual growth rate and Cuddy Della Valle Index for instability index were used. Results showed that the area of pulses in Andhra Pradesh, Karnataka, Gujarat, Maharashtra, Rajasthan and Madhya Pradesh increased at a highly significant annual growth rate, but the area in Uttar Pradesh declined at a significant rate per annum (-0.81%) during the overall period. Production and productivity of pulses in Andhra Pradesh, Karnataka, Gujarat, Maharashtra, Rajasthan and Madhya Pradesh were found to be increased at a highly significant rate annually, but production declined at a significant rate (-0.56%) in Uttar Pradesh. Instability of area in Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra and Madhya Pradesh was low, while in Gujarat and Rajasthan it was moderate. Production instability was medium in all the major states except Uttar Pradesh (low) and Rajasthan (high). Yield instability was low in Uttar Pradesh and Madhya Pradesh, while medium in Andhra Pradesh, Karnataka, Maharashtra and Rajasthan. Gujarat was the only state that showed high instability in yield. All India registered low instability in area and productivity, whereas medium in production.

Pooja *et al.* (2023) developed a clear portrayal of the area and production of pulses in India. Regression modeling was applied for both the area and production of Pulses in India for a period of 71 years (1950-51 to 2020-21) using linear, logarithmic, quadratic, cubic, power and exponential models. The results concluded that the cubic model showed better performance compared to other models for the prediction of area and production of pulses for India, with maximum accuracy.

Rani *et al.* (2023) conducted a study to examine the growth performance and relative contribution of area and productivity to the change in Mungbean production in Nagaur, Jodhpur and Pali districts of Rajasthan from 2000-01 to 2019-20. The study period was bifurcated into two sub-periods: 2000-01 to 2009-10 (sub-period I) and 2010-11 to 2019- 20 (sub-period II). In sub-period I, the interaction effect was the highest (165.30 %), followed by the productivity effect (162.72 %). In sub-Period II, the area contributed a maximum of 122.25 % to the change in Mungbean production. Overall, the contribution of the interaction effect (59.03 per cent) was the highest, followed by area (26.47 per cent) and the productivity effect (14.50 per cent) to the change in Mungbean production in Rajasthan.

Balai *et al.* (2024) reported the growth, decomposition and instability in area, production and productivity of rabi pulse crops, viz., gram and lentil, in Madhya Pradesh.

The study was based on secondary time series data. The time series data of area, production and productivity of rabi pulse crops, viz., gram and lentils, have been taken from 1992-93 to 2021-22. The study period (1992-93 to 2021-22) was divided into four periods. Three analyses were carried out in the study, viz. CAGR by fitting an exponential function, Decomposition analysis by the Minhas and Vaidyanthan model and Instability analysis by the Cuddy-Della Valle index. The findings of the study observed that during the entire study period, the area under gram increased at the rate of 0.32 per cent per annum, while the production and productivity had significantly increased at the rate of 2.20, 1.88 per cent, respectively, per annum in Madhya Pradesh. The production of gram in Madhya Pradesh might have increased due to significant productivity growth. At the same time, the area, production and productivity of lentil recorded positive and significant growth rates at the rate of 3.07, 2.52 and 0.54, respectively, in Madhya Pradesh. During the overall period, the yield effect was more responsible for the growth in gram and lentil production. The highest instability was observed in the production of gram and lentil crops during all periods in Madhya Pradesh.

Singh and Usmani (2024) reported pulse production growth in Uttar Pradesh and Uttarakhand and identified efficient cropping zones for both states. The total change in production was decomposed into three effects, i.e., the area effect (ΔA. ΔY), the yield effect (ΔY. ΔA) and the interaction effect (ΔA. AY). The relative spread index (RSI) and relative yield index (RYI) were computed to identify the potential cropping districts for different pulses grown in Uttar Pradesh and Uttarakhand. The results from Uttar Pradesh are highly encouraging, indicating that the yield effect has primarily contributed to the growth in pulse production.

Singh and Usmani (2024) studied the growth and instability of pulses in Uttar Pradesh and Uttarakhand. Uttar Pradesh is identified as the major contributor to pulse production and since Uttarakhand is a part of Uttar Pradesh, the analysis was carried out for these two states. The analysis revealed the importance of MSP and considered it as the primary reason for the decrease in import of pulses and increasing self-reliance.

Chapter 3

MATERIALS AND METHODS

A proper methodology, defining data collection and analysis techniques, must be applied to achieve the many objectives of the study. The primary goal of this chapter is to give a brief overview of the materials that comprise the database for the study and the primary statistical methods used in the analysis. The materials and methodologies used in this investigation have been described in the following headings of sections.

3.1 Description of the study area
3.2 Selection of crops
3.3 Collection of data
3.4 Estimation of Growth Rate
3.5 Statistical Models used in the study
3.6 Computation of Various Statistical Coefficients and Measures

3.1 Description of the study area

The study was undertaken for the Mirzapur district of Uttar Pradesh (India).

3.2 Selection of crops

The major pulse crops of Mirzapur district, such as Arhar, Gram, Lentil, Urad and Pea, are selected for the present investigation.

3.3 Collection of data

This study utilizes time-series data on area, production and yield of pulse crops from 1993-94 to 2021-22 pertaining to Mirzapur District of Uttar Pradesh. The data were obtained from the *Sankhikiya Patrika* (Statistical Bulletin) published by the Economics and Statistics Division, Planning Department, Government of Uttar Pradesh, and the Directorate of Economics and Statistics, Department of Agriculture Cooperation & Farmers Welfare, Government of India.

3.4 Estimation of Growth Rate

The early work of Thomas Malthus (1798) and C. F. Gauss (1805) continues to influence us today in forming our concepts of growth rates. Malthus's population growth theory centered on the significance of models of exponential growth and Gauss & Legendre's work in mathematics and statistics that allowed us to examine and model growth rates.

To determine the growth rates of the area, production and productivity of different pulse crops in the Mirzapur District of Uttar Pradesh, both Linear Growth Rate (LGR) and Compound Growth Rate (CGR) methods were applied. Three-year and five-year moving averages were applied to smooth out random fluctuations in the data.

3.4.1 Linear Growth Rate

The equation gives a linear function:

$$Y_t = a + bt$$

where;

t is the Time in years, an independent variable, Y_t is the trend value of the dependent variable and a and b are constants.

The above equation is fitted by using the ordinary least squares method of estimation.

The linear growth rate is given by

$$\text{Linear growth rate (LGR\%)} = \frac{\hat{b}}{\bar{Y}} \times 100$$

where;

$\hat{b}$ is the estimated value of b and $\bar{Y}$ is the mean of variable Y.

3.4.2 Compound Growth Rate

This formula determines the average yearly growth rate required to increase the crop's value from its starting point to its highest possible value over a particular number of years, assuming that growth occurs at an average rate compounded annually. The compound growth model is given by

$$y_t = a(1 + r)^t$$

where;

y_t is the time-series value of variable Y at time t, 'a' is a scalar quantity and 'r' denotes the compound growth rate.

Taking logarithms on both sides of the above equation, we have linearised this as

$$\log y_t = \log a + t\{\log(1+r)\}$$

$$i.e., \qquad Y_t = A + Rt$$

Where, $Y_t = \; log y_t, \; A \; = \log a$, and $R = \; log\;(1+r)$.

Fitting the above model by ols technique, we get

$$\hat{a} = antilog\;(A)$$

$$\hat{r} = antilog(R) - 1$$

Here, $\hat{r}$ denotes the estimated compound growth rate (CGR) and is generally expressed in terms of percentage as follows:

$$\hat{r} = [antilog(R) - 1] \times 100$$

3.5 Statistical Models used in the study

3.5.1 Linear Regression Model:

The linear model is given by:

$$\boldsymbol{Y_t = a + bt + \varepsilon_t}$$

where;

Y_t represents the dependent variable (area, production, yield), *t* (the independent variable) denotes time in years, *a* is the model's intercept, *b* is the regression coefficient and ε_t is the normally distributed error term, $\varepsilon_t \sim N(0, \sigma^2)$. (Gauss, C.F. and Legendre, A.M. 1805)

3.5.2 Quadratic Model:

Appropriate for data exhibiting peaks or troughs, the quadratic model is given by (Zaremba, 1978):

$$\boldsymbol{Y_t = a + bt + ct^2 + \varepsilon_t}$$

where;

a is the model's intercept, *b* is the regression coefficient and *c* represents an additional regression coefficient related to the square of time, making the model capable of capturing parabolic trends.

3.5.3 Cubic Model:

The cubic model is given by:

$$\boldsymbol{Y_t = a + bt + ct^2 + dt^3 + \varepsilon_t}$$

For data showing multiple peaks or troughs, the cubic model incorporates a third-degree polynomial, allowing for more complex curve fitting.

where;

a is the model's intercept and *b, c* and *d* are coefficients. (Zaremba, 1978)

3.5.4 Logarithmic Model:

Logarithms, and by extension logarithmic models, were primarily developed by John Napier (1614). The logarithmic model is given by:

$$\boldsymbol{Y_t = a + b ln(t) + \varepsilon_t}$$

employs the natural logarithm of time, facilitating data analysis following a logarithmic trend.

where;

a is the model's intercept and *b* is the regression coefficient.

3.5.5 Power Model:

The concept of regression, which includes power regression models, is largely attributed to Sir Francis Galton. The power model is given by:

$$\boldsymbol{Y_t = at^b . e^{\varepsilon_t}}$$

or transformed into

$$\boldsymbol{lnY_t = ln\,(a) + b ln(t) + \varepsilon_t}$$

in its logarithmic form for linearization, this approach addresses data with varying growth rates, akin to exponential models but with differential increase or decrease rates.

where;

a is the model's intercept and *b* is the regression coefficient.

3.5.6 Exponential Model:

The exponential model is given by:

$$\boldsymbol{Y_t = ae^{bt} + \varepsilon_t}$$

or transformed into

$$\boldsymbol{lnY_t = ln\,a + (bt) + \varepsilon_t}$$

for linear regression applications, this model fits data that grows or declines exponentially.

where;

a is the model's intercept and *b* is the regression coefficient. (Malthus, T.R. 1798)

3.6 Computation of Various Statistical Coefficients and Measures

3.6.1 Coefficient of Variation

The coefficient of variation (CV) is a standardized measure of dispersion and is a unitless quantity. It was first introduced by Karl Pearson (1857-1936). It is generally expressed in terms of percentage as follows:

$$CV(Y) = \frac{SD(Y)}{\bar{Y}} \times 100$$

where;

$S.D.(Y)$ denotes the standard deviation of the variable Y (which may be either Area, Production, or Yield, as the case may be). Also, $\bar{Y}$ denotes the mean of the variable Y.

3.6.2 Coefficient of Determination

The coefficient of determination (R^2) is given by:

$$R^2 = 1 - \frac{\sum_{t=1}^{n}(y_t - \hat{y}_t)^2}{\sum_{t=1}^{n}(y_t - \bar{y})^2}$$

where;

y_t denotes the time-series value of variable Y at time t. Also, $\bar{y}$ denotes the mean value of the variable Y. Moreover, $\hat{y}_t$ represents the trend value of the variable Y at time t, obtained by fitting the respective statistical model (such as linear or exponential model or other models). (Fisher, R.A. 1925)

3.6.3 Mean Absolute Percentage Error (MAPE)

The concept of Mean Absolute Percentage Error (MAPE) is attributed to Armstrong (1985). The Mean absolute percentage error is given by:

$$MAPE = \frac{100}{n}\sum_{t=1}^{n}\left|\frac{y_t - \hat{y}_t}{y_t}\right|$$

3.6.4 Root Mean Square Error (RMSE)

The root mean square error (RMSE) is given by:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_t)^2}$$

where;

y_t is the actual value and $\hat{y}_t$ is the forecast value. (Gauss, C.F. 1809)

3.6.5 Instability Index

To assess the level of instability in production, area and crop yield, the instability index developed by Cuddy-Della Valle (CDV, 1978) is utilized. The computation of this index is achieved through the following formula:

$$I = CV\sqrt{1 - R^2}$$

3.6.6 Decomposition Analysis

The concept of decomposition analysis in the area-productivity-interaction framework was first introduced by Minhas and Vaidyanathan (1965).

I. An additive decomposition analysis can be applied to estimate the contribution of area, productivity and the interaction of the two factors to the total production. This method involves breaking down the total change in production into three main components.

$$\Delta P = A_0 (Y_n - Y_0) + Y_0 (A_n - A_0) + \Delta A \Delta Y$$

$$1 = [(Y \Delta A) / \Delta P] + [(A \Delta Y) / \Delta P] + [(\Delta A \Delta Y) / \Delta P]$$

where;

ΔP = Change in production

A_0 = Area in the base year

A_n = Area in the current year

Y_0 = Yield in the base year

Y_n = Yield in the current year

ΔA = Change in Area ($A_n - A_0$)

ΔY = Change in Yield ($Y_n - Y_0$).

II. In decomposition analysis, especially when analyzing changes in mean yield and mean area, we can use a method that breaks down the overall change into its components.

Using a basic decomposition formula, we can express the change in production as the sum of changes due to yield and area:

$$\Delta P = \text{Mean Yield Effect} + \text{Mean Area Effect} + \text{Mean Interaction Effect}$$

The change in mean yield while keeping the area constant:

$$\text{Mean Yield Effect} = (\overline{Y}_2 - \overline{Y}_1) \times \overline{A}_1$$

The change in the mean area while keeping the yield constant:

$$\text{Mean Area Effect} = (\bar{A}_2 - \bar{A}_1) \times \bar{Y}_1$$

The combined effect of changes in both mean yield and mean area:

$$\text{Mean Interaction Effect} = (\bar{Y}_2 - \bar{Y}_1) \times (\bar{A}_2 - \bar{A}_1)$$

where;

$\bar{Y}_1$ and $\bar{A}_1$ represents the initial mean of yield and area.

$\bar{Y}_2$ and $\bar{A}_2$ represents the final mean of yield and area.

ΔP represents the total Change in production.

Initial Mean ($\bar{Y}_1$ and $\bar{A}_1$) The variable's average value during the data set's beginning period (1993-94 to 2007-08).

Final Mean ($\bar{Y}_2$ and $\bar{A}_2$) The variable's average value during the data set's end time (2007-08 to 2021-22).

3.6.7 Percentage Change in Production, Area or Yield of the Crop

$$\%\ change\ in\ Y = \frac{Value\ of\ Y\ in\ the\ current\ year - Value\ of\ Y\ in\ the\ base\ year}{value\ of\ Y\ in\ the\ base\ year} \times 100$$

where;

Y = Production, Area, or Yield, as the case may be.

Tools and Software

Statistical software packages (e.g., R, Python, SPSS) will be used for data analysis and model building, while graphical tools and libraries (e.g., my curvefit, Matplotlib, ggplot2) will be applied to generate tables and graphical representations of production trends.

* * *

Chapter 4

RESULTS AND DISCUSSION

The present chapter demonstrates the results and discussion with the following analysis of Pulses:

4.1 Growth rates and trends of pulse crops in the Mirzapur district of Uttar Pradesh.
4.2 Assessment of the performance of various statistical models related to pulse crop production.
4.3 Validation of models based on various statistical coefficients and measures, including decomposition analysis.
4.4 Policy recommendations based on findings of the study undertaken.

The comprehensive analysis and findings of the studies mentioned above are explained in the subsequent subsections.

4.1 Growth rates and trends of pulse crops in the Mirzapur district of Uttar Pradesh

This study utilizes secondary time-series data on pulse production from 1993-94 to 2021-22 in the Mirzapur District of Uttar Pradesh. Three-year and five-year moving averages were applied to smooth out random fluctuations in the data. Furthermore, the linear and compound growth rates (CGRs) are computed for area, production and yield of pulses in Mirzapur and the findings are summarized in Tables 4.1.1 to 4.1.3 and 4.1.4 to 4.1.6, respectively.

4.1.1 Linear Growth Rate (LGR)

Table 4.1.1 Linear growth rate for the area of pulses

Pulses	Overall-year LGR (%)	Three-year moving average LGR (%)	Five-year moving average LGR (%)
Arhar	-0.53*	-0.63	-0.60
Gram	-1.70	-1.77	-1.80
Pea	-0.56	-0.72	-0.97*
Lentil	-0.05	-0.13	-0.31
Urad	-1.11*	-1.18	-1.52

* Imply significance at a 5% level of significance

Table 4.1.1 indicates that the Linear growth rate analysis of pulse crop area Arhar, Gram, Pea, Lentil, and Urad by overall-year linear growth rate (LGR), three-year moving average LGR, and five-year moving average LGR indicates a long-term negative and rising trend. The total LGR numbers reveal that all five pulses have registered a decline, with the highest decline in Gram at -1.70%, followed by Urad at -1.11%, Pea at -0.56%, Arhar at -0.53%, and Lentil at -0.05%. This is a general decline in the performance of the pulses, especially in Gram and Urad, which may be a result of lower area, reduction in yield, or other agronomic and economic challenges. When smoothed against a three-year moving average, the decline is also sharper, with Gram declining further to -1.77 percent and Urad declining further to -1.18 percent. In comparison, Pea and Arhar also decline further at -0.72 percent and -0.63 percent, respectively. Lentil, despite remaining negative, still experiences the lowest decline at -0.13 percent, indicating relative strength in the past few years. The five-year moving average LGR is also showing even more serious deterioration, with Gram falling to -1.80 percent and Urad to -1.52 percent, which indicates not just that the negative growth continued but that it intensified over a longer period. This pattern aligns with the findings of Srivastava *et al*. (2013), Sharma *et al*. (2014) and Bisht and Kumar (2018), who also reported declining growth in pulse crop area in eastern Uttar Pradesh due to factors such as land reallocation and market price instability.

Pea (-0.97%), Arhar (-0.60%), and Lentil (-0.31%) follow a declining trend like these. This trend among the three measures indicates that things declined over time, most prominently in the case of Gram and Urad. The rise in negativity of growth rates with longer averaging periods indicates a structural and ongoing decline rather than a transitory movement. These observations indicate the necessity of immediate care and intervention by regional strategies, improved varieties, improved crop management practices, guaranteed procurement, and price support to turn back the declining trends and render pulse production feasible in the region.

Table 4.1.2 Linear growth rate for the production of pulses

Pulses	Overall-year LGR (%)	Three-year moving average LGR (%)	Five-year moving average LGR (%)
Arhar	-0.82	-0.89*	-0.70
Gram	-1.09*	-0.95*	-0.83*
Pea	-0.80	-0.90	-1.09*
Lentil	0.78	0.71	0.52
Urad	0.73	0.89	0.55

* Imply significance at a 5% level of significance

Linear growth rate analysis of key pulse crops Arhar, Gram, Pea, Lentil, and Urad for Overall-year, three-year moving average, and five-year moving average LGR in Table 4.1.2 indicates mixed trends for various crops. While the growth trend in the case of Arhar, Gram, and Pea is always negative, the growth of Lentil and Urad is positive during the study period. The year-round LGR reflects Gram with the highest negative rate of -1.09 percent, followed by Arhar (-0.82%) and Pea (-0.80%), and these are reflective of the uniform downtrend in their production. Lentil and Urad, on the other hand, have good all-around growth rates of 0.78 percent and 0.73 percent, respectively, and this is a sign of improvement in their production performance that can perhaps be attributed to good agronomic management, superior variety, or policy support.

The three-year moving average LGR gives a less smoothed image, with Arhar and Pea declining even deeper at -0.89 percent and -0.90 percent, respectively, and Gram improving to -0.95 percent. Conversely, that of Urad increases to 0.89 percent, and Lentil still has a robust positive trend of 0.71 percent, supporting their steady performance in recent years. The medium-term trend in production is as indicated by the five-year moving average LGR, with Pea dipping to a lower -1.09 percent, yet reflecting a production crisis that has deepened, while Arhar and Gram improved minutely to -0.70 percent and -0.83 percent, respectively. Lentil and Urad still reflect improving trends, though with growth rates moderating to 0.52 percent and 0.55 percent, respectively.

In total, the analysis shows a sharp and continued fall in the yield of Arhar, Gram, and Pea, especially the latter, which is not showing improvement with time. Alternatively, Lentil and Urad show increasing and relatively stable growth, which establishes the increasing significance of pulse production. These divergent trends are the result of the call for targeted interventions, e.g., enhanced seed technology, incentives in production and extension on declining crops, as well as to maintain the momentum of progress in crops such as Lentil and Urad through ongoing research and development, support to infrastructure, and access to markets.

Table 4.1.3 Linear growth rate for the yield of pulses

Pulses	Overall-year LGR (%)	Three-year moving average LGR (%)	Five-year moving average LGR (%)
Arhar	-0.27	-0.23	-0.08
Gram	0.66	0.83*	0.97
Pea	-0.33	-0.27	-0.21
Lentil	0.81*	0.80*	0.80
Urad	1.77*	1.98	2.03

* Imply significance at a 5% level of significance

Table 4.1.3 provides the overall-year, three-year moving average and five-year moving average LGR analysis of the major pulse crops, i.e., Arhar, Gram, Pea, Lentil and Urad. Five-year moving average LGR shows a mixture of negative and positive trends. Arhar and Pea show a declining trend in growth in yield consistently, whereas Gram, Lentil, and Urad show positive growth, which reflects a rise in Yield during the year of study. In the Overall year, LGR indicates Pea with the highest negative yield growth rate at -0.33 percent, and Arhar at -0.27 percent, reflecting a yield reduction due to non-productive varieties, unfavorable climatic conditions, or wrong agronomic practices. On the other hand, Urad has the maximum rate of yield increase of 1.77 percent for the whole year, while that of Lentil and Gram is 0.81 percent and 0.66 percent respectively, which reflects efficient intervention in these crops.

Three-year rolling average LGR also reflects these trends, and Pea and Arhar are a bit better during the fall in yield at -0.27 percent and -0.23 percent, respectively, still in negative. Gram's momentum to increase yield to 0.83 percent, Lentil remains constant at 0.80 percent, and Urad continues to get better at 1.98 percent. Five-year moving average LGR, or medium-run trends, registers an increasing run-up in Gram (0.97%) and Urad

(2.03%), but levels at 0.80 percent for Lentil. Arhar yield decline decreases to -0.08 percent, reflecting marginal stabilisation, while Pea shows a negative trend of -0.21 percent.

Altogether, the trend shows that Arhar and Pea are showing declining yields, whereas Gram, Lentil, and most importantly of all, Urad are always on the ascending trajectory. The long-term and increasing growth of Urad and Gram are signs of superior agronomic management, superior varieties, and superior use of the inputs. These results call for continued efforts to increase the production of backward crops like Arhar and Pea through improved research, improved cultivation methods, and support on inputs, while sustaining and reinforcing the improvement in Yield gained in Gram, Lentil, and Urad in the overall development of the pulse industry.

4.1.2 Compound Growth Rate (CGR)

Table 4.1.4 Compound growth rate for the area of pulse

Pulses	Overall-year CGR (%)	Three-year moving average CGR (%)	Five-year moving average CGR (%)
Arhar	-0.55*	-0.62	-0.59
Gram	-1.63	-1.70	-1.74
Pea	-0.56	-0.69	-0.95*
Lentil	-0.10	-0.15	-0.32
Urad	-1.07*	-1.14	-1.47

* Imply significance at a 5% level of significance

Compound growth rate (CGR) calculation of the region brought by principal pulse crops Arhar, Gram, Pea, Lentil, and Urad is as follows in Table 4.1.4, depicting a sharp and consistent decline in all crops when in terms of year-round values, movement of three-year average, and movement of five-year average. Year-over-year CGR percentages indicate that Gram has witnessed the sharpest drop in area, which declined by -1.63%, followed by others, such as Urad (-1.07%), Pea (-0.56%), and Arhar (-0.55%). There is no such dismal report about Lentil, with the decline being the least, though negative at -0.10%, which reflects a relatively stable pattern when compared with others.

Since the trends are smoothed with a three-year moving average, the trend of decline is visible. The CGR of Gram declines even further to -1.70%, and Urad also declines even further to -1.14%, once again showing the steady downward progress of area. Pea and Arhar also decline even further by -0.69% and -0.62% respectively. Lentil shows a tiny increase in the rate of decline to -0.15%, yet remains the least impacted of the group.

On a five-year moving average, representing the larger structural trend, the fall is sharper. Gram's CGR falls to -1.74%, and Urad to -1.47%, as a sign of a chronic and persistent fall in area under these crops. Pea also shows a very sharp fall at -0.95%, as a higher difficulty in its cultivation is recorded. The Arhar region is still comparatively declining by -0.59%, and Lentil, while still being the most stable among the group, has its CGR fall to -0.32%.

Overall, the examination observes that the foundation of the pulse crops is falling steeply and persistently, particularly for Gram, Urad, and Pea. These trends result in root causes such as financial non-viability, competitiveness of the crops, adverse climatic conditions, or policy disfavor. The progressively worsening CGRs for the three periods indicate that there is an immediate need to prevent further decline. Such interventions as increasing the MSP, providing input subsidies, promoting drought-resistant and high-yielding varieties, and improving irrigation and extension services would prove useful in halting the decline and reviving the growth of pulses in the region.

Table 4.1.5 Compound growth rate for the production of pulses

Pulses	Overall-year CGR (%)	Three-year moving average CGR (%)	Five-year moving average CGR (%)
Arhar	-0.79	-0.82	-0.63
Gram	-1.00*	-0.88*	-0.79*
Pea	-0.92	-0.94	-1.11*
Lentil	0.65	0.68	0.52
Urad	0.55	0.77	0.52

* Imply significance at a 5% level of significance

Compound growth rate (CGR) analysis of the major pulse crops' yield, like Arhar, Gram, Pea, Lentil, and Urad, as shown in Table 4.1.5, shows a fluctuating trend with some showing negative growth rates while others increase over intervals. Year-round CGR values reflect that Gram (-1.00%), Pea (-0.92%), and Arhar (-0.79%) show a decreasing production trend for the whole study period, reflecting long-term problems in production. However, Lentil and Urad are shown with growth rates of 0.65% and 0.55%, respectively, showing improved performance in production.

Dropped in the case of the three-year moving average from the volatility in the lower terms, Gram also picks up a fraction to -0.88%, and Arhar drops a fraction more to -0.82%. Pea picks up a sharper fall to -0.94%, however, reflecting unrelenting pressure on output. Lentil and Urad, however, continue to move north with growth rates of 0.68% and 0.77%, respectively, thus reflecting the unrelenting rise in their output levels in the short run.

There is also a change in the five-year moving average reflecting medium-term trends. Arhar CGR turns around to -0.63%, Gram also does to -0.79%, indicating slackening of decline over long periods. Pea falls even lower to -1.11%, which reflects a drastic and consistent decline in output. Lentil and Urad, however, reflect positive but comparatively lower growth rates at 0.52%, which reflects stability and an increase in Yield over long periods of time.

Generally, the trend analysis indicates volatility in the production trend of the pulse crops. Arhar, Gram, and Pea have regular and negative downtrends in production, and among them, Pea has a downtrend for all time horizons. Lentil and Urad show positive and uniform growth, and it may be due to enhanced use of varieties, efficient managerial practices, and good weather. Such findings underscore the need for combined action in restricting falling trends in crops like Gram, Arhar, and most importantly, Pea. At the same time, sustained support and investment should be ensured to construct and consolidate improvements in Lentil and Urad production.

Table 4.1.6 Compound growth rate for the yield of pulses

Pulses	Overall-year CGR (%)	Three-year moving average CGR (%)	Five-year moving average CGR (%)
Arhar	-0.24	-0.22	-0.07
Gram	0.64	0.83*	0.95
Pea	-0.36	-0.30	-0.22
Lentil	0.74*	0.80*	0.80
Urad	1.64*	1.88	1.98

* Imply significance at a 5% level of significance

Compound growth rate (CGR) calculation of the yield of major pulse crops like Arhar, Gram, Pea, Lentil and Urad as revealed in Table 4.1.6, points towards a clear deviation in performance where certain of the crops have been able to record a rise in their production, while others have remained stagnant or in a decline. Aggregate-year CGR indicates that Urad has seen the highest positive yield growth of 1.64%, followed by Lentil (0.74%) and Gram (0.64%), because these have been facing positive Yield growth during the research phase. Alternatively, Pea (-0.36%) and Arhar (-0.24%) have seen a yield reduction, i.e., repeated problems concerning production technology or environmental resistance.

Three-year rolling CGR that levels out short-run fluctuations attests to the same. Urad again converges to 1.88%, reflecting rising Yield (day to day), hopefully on the back of technological innovations or sound agro-management practices. Gram and Lentil also reflect the rising trend of yields at 0.83% and 0.80%, respectively. On the other hand, Pea yield falls to -0.30%, while Arhar improves slightly to -0.22%, but both are still in negative territory. The five-year CGR rolling average, which is a gauge of long-term yield performance, once again reiterates the recovery pattern in Urad, now at an all-time high of 1.98%, with very consistent incremental improvement from year to year. Gram also continues to rise at 0.95%, and Lentil shows improvement in a consistent 0.80% increase in yield. Conversely, Arhar exhibits stabilization since its loss is only by -0.07%, and Pea continues to be negative at -0.22%, but continues to lag in its yield performance, Sharma *et al*. (2013), who also reported positive growth in area and production of lentil but declining yield during the post-Technology Mission period. Similarly, Ardeshna *et al*. (2011) found that gram and total pulses in Gujarat showed mixed growth trends in area and yield, with production increases driven mainly by area expansion. Devi and Mehla (2022) confirmed the significance of positive yield growth across chickpea and black gram in India using CGR models, highlighting the robustness of compound trend estimation methods in pulse research.

On the whole, yield-based evaluation depicts spectacular improvement in Urad, Lentil, and Gram, which have demonstrated sustained progress right across all the stages, indicating successful technology, variety, or management intervention. Pea and Arhar continue to lag in yield increase, for which special attention is needed. These observations necessitate redoubled efforts towards enhancing lagging crop yield performance through optimal exploitation of inputs, stress-tolerant cultivars, precision farming, and extension. At the same time, the extended yield increments in Urad, Gram, and Lentil must continue and be emulated to facilitate sustainable pulse Yield growth.

4.2 Assessment of the performance of various statistical models related to pulse crop production

This study used a variety of models, including linear and nonlinear (Ratkowsky, 1990 and Bard, 1974) and time-series models. Tables 4.2.1 to 4.2.15 summarize the results on fitting models to the data on area, production and yield, respectively. Moreover, Fig. 4.2.1 to 4.2.45 demonstrates the best-fitted model graph for the area, production and yield of pulses. The performance of different regression models for the area, production and yield under pulse cultivation was confirmed based on some statistical parameters like R-square. Actual values, 3-Year Moving Average (3MA), and 5-Year Moving Average (5MA) were used to identify the most suitable model for every condition. These findings are consistent with Pooja *et al*. (2023), who demonstrated that cubic models outperformed other forms in predicting area and production of pulses in India. Similarly, Gajbhiye *et al*. (2010) emphasized the utility of nonlinear models like quadratic and cubic in achieving improved model fit for agricultural data. Balai *et al*. (2024) also confirmed the superiority of such models in evaluating the performance and variability of gram and lentil production using long-term datasets.

Table 4.2.1 Model Evaluation for the area of Gram in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	538618.6**	-260.58**			0.79
	3MA	557679**	-270**			0.84
	5MA	561979.8**	-272.05**			0.88
Logarithmic	Actual	3997500**	-523629**			0.79
	3MA	4143155**	-542760**			0.84
	5MA	4176411**	-547116**			0.88
Quadratic	Actual	55368953	-54873.4	13.59881		0.91
	3MA	57408916.74	-56867.4	14.08		0.95
	5MA	55983931.72	-55419	13.71		0.98
Cubic	Actual	**-4024212168.2**	**6040245**	**-3021.85**	**0.50**	**0.92**
	3MA	**-3241941181**	**4870075.60**	**-2438.37**	**0.40**	**0.96**
	5MA	**-413380201****	**6198089.25****	**-3097.5****	**0.51****	**0.98**
Power	Actual	260.19**	-32.94**			0.80
	3MA	272.16**	-34.52**			0.86
	5MA	277.87**	-35.27**			0.90
Exponential	Actual	42.55**	-0.01**			0.80
	3MA	44.12**	-0.01**			0.86
	5MA	44.87**	0.01**			0.90

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.1 shows that for the actual data, the cubic model was the best among all the models. It possessed a maximum R-square (0.92), which shows high explanatory power of the model.

According to the 3-Year Moving Average (3MA), the cubic model performed best with the maximum R-square value of 0.96, suggesting the optimal performance of the model. The quadratic model was also competitive, with its R-square (0.95) being a bit lower than the cubic model.

By taking into account the 5-Year Moving Average (5MA), the cubic model was the best in all the statistical parameters in both cases. It had the highest value of R-square (0.98). These support the high-level predictive accuracy and stability of the model on smoothed data. The quadratic and linear models were defeated substantially in all the major parameters.

Summary On all three databases, actual, 3MA, and 5MA, the cubic regression model was the most accurate and best-fitting model of the trend in terms of gram cultivation in Mirzapur district. Its stability in R-square under all scenarios is a testament to its consistency and appropriateness in modeling such time series data in agriculture. The cubic model is thus proposed to make further forecasting and policy analysis of the gram cultivation region in this district.

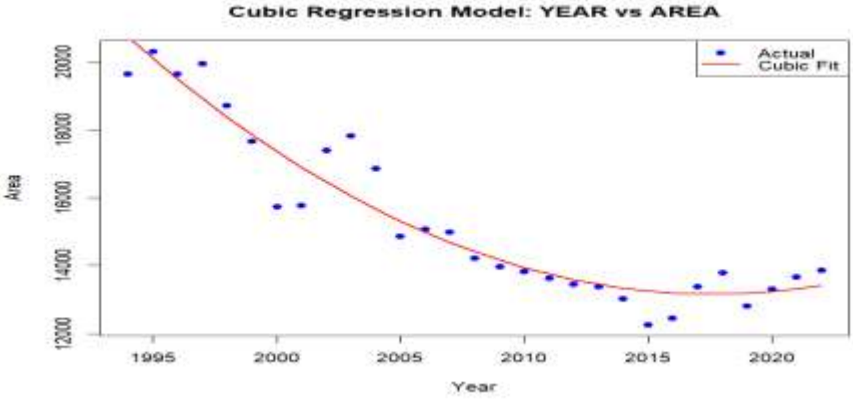

Fig 4.2.1 Fitted Trends of Area of Gram in Mirzapur district of UP

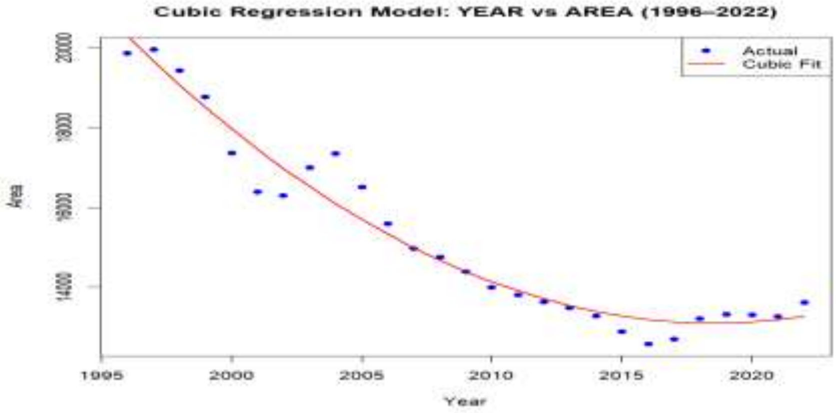

Fig 4.2.2 Fitted Trends of Area for 3-year moving average of Gram in Mirzapur district of UP

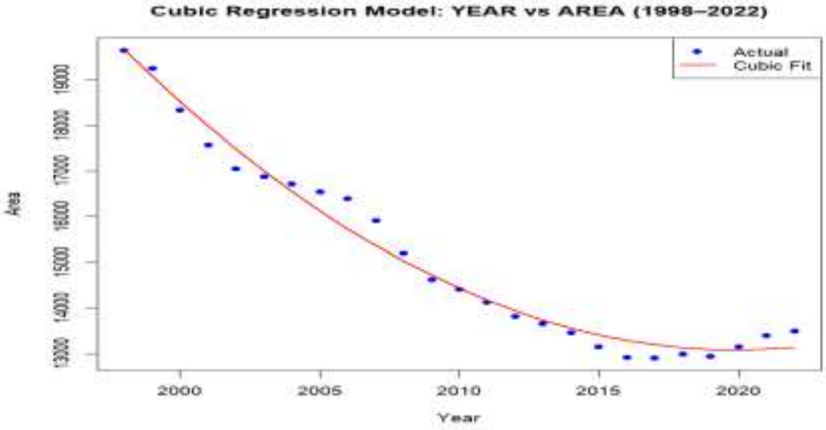

Fig 4.2.3 Fitted Trends of Area for 5-year moving average of Gram in Mirzapur district of UP

Table 4.2.2 Model Evaluation for the production of Gram in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	3658500**	-1742.54*			0.17
	3MA	312867**	-1479.94**			0.27
	5MA	2714661**	-1274.39**			0.31
Logarithmic	Actual	2683747*	-350801*			0.17
	3MA	2281185	-29791			0.27
	5MA	1967116**	-256617**			0.31
Quadratic	Actual	1309572997.21**	-1302477**	323.88**		0.50
	3MA	984509781.45**	-97848**	243.15**		0.63
	5MA	915824660.51**	-909853**	226.01**		0.72
Cubic	Actual	**69251998727**	**-102812196**	**50877.06**	**-8.39**	**0.51**
	3MA	**15148112007**	**-22129087.8**	**10771.17**	**-1.74**	**0.63**
	5MA	**-78714326969**	**117942951.1**	**-58905189**	**9.80**	**0.75**
Power	Actual	165.59**	-20.20*			0.16
	3MA	146.92**	-17.74**			0.27
	5MA	133.92**	-16.03**			0.31
Exponential	Actual	32.11**	-0.010*			0.16
	3MA	29.65	-0.008			0.26
	5MA	27.94	-0.007			0.31

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

According to Table 4.2.2, the cubic model recorded the highest R-square (0.51) and, among all models, with a better ability to explain variability in production. Analogously, the quadratic model also performed comparatively well, R-square (0.50). Therefore, the cubic model is best suited for actual data models, though with moderate residual errors.

For 3-Year Moving Average (3MA) data, too, the cubic model fared the best with an R-square (0.63). This is considerably improved compared to the actual data results, indicating higher model stability and accuracy after smoothing. The quadratic model was ranked as the second-best R-square (0.63) than the Cubic model. This makes the latter the best model for 3MA data as well.

Among all models, regardless of time base, in the 5-Year Moving Average (5MA), the cubic model performed better than all the other models by a wide margin. It provided the highest R-square (0.75) among all models. These indicators indicate high model fit, low prediction error, and high reliability, thereby making the cubic regression model the best fit model for the 5MA production data of grams.

Finally, the cubic regression model was found to be the best-fit model for the modeling of the trend in gram production in all three types of data. Performance of the model became better stepwise data smoothing from real data to 3MA and then 5MA as reflected by rising R-square values (0.51, 0.63, and 0.75, respectively). Hence, for policy formulation, forecasting, or any strategic intervention in regard to Gram production of the Mirzapur area, a cubic model on the basis of 5-Year Moving Average data is highly recommended.

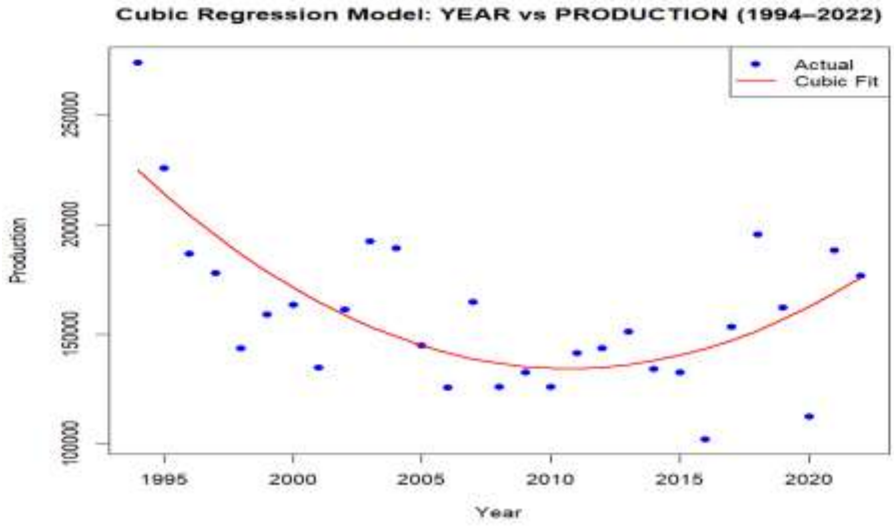

Fig 4.2.4 Fitted Trends of Production of Gram in Mirzapur district of UP

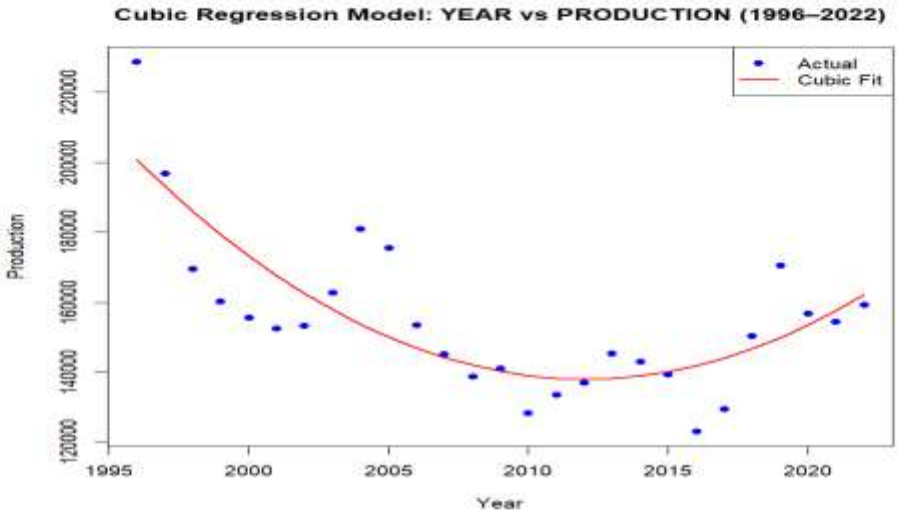

Fig 4.2.5 Fitted Trends of Production for 3-year moving average of Gram in Mirzapur district of UP

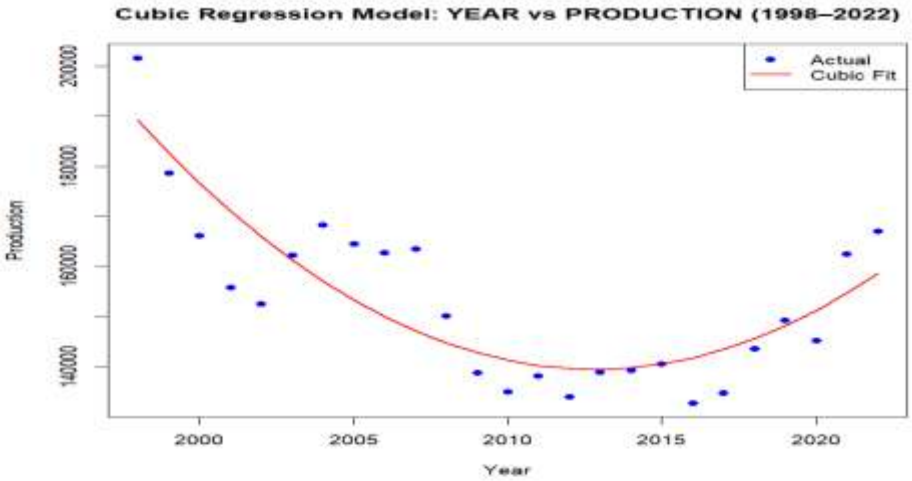

Fig 4.2.6 Fitted Trends of Production for 5-year moving average of Gram in Mirzapur district of UP

Table 4.2.3 Model Evaluation for the yield of Gram in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	-128.35	0.06			0.11
	3MA	-160.85**	0.08**			0.41
	5MA	-187.41**	0.09**			0.65
Logarithmic	Actual	-1042.38	138.43			0.11
	3MA	-1289.53**	170.89**			0.41
	5MA	-1491.51**	197.43**			0.65
Quadratic	Actual	48184.25**	-48.05**	0.01**		0.29
	3MA	29900.72**	-29.84**	0.007**		0.57
	5MA	29105.65**	-29.04**	0.007**		0.80
Cubic	Actual	**500983**	**-7461.03**	**3.70**	**-0.0006**	**0.32**
	3MA	**2178726.58**	**-3238.69**	**1.60**	**-0.0002**	**0.58**
	5MA	**-2970270.53**	**4447.70**	**-2.22**	**0.0003**	**0.82**
Power	Actual	-94.60	12.74			0.10
	3MA	-123.47**	16.53**			0.42
	5MA	-141.81**	18.94**			0.66
Exponential	Actual	-10.44	0.006			0.10
	3MA	-14.23**	0.008**			0.42
	5MA	-16.64**	0.009**			0.66

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.3 shows that for the actual data, the cubic model yielded the overall best fit among the models. It gave an R-square (0.322), higher than most other models of this class.

Upon application to the three-year moving average (3MA) series, the cubic model continued to give the best performance with R-square (0.5803). The performance was poor compared to actual data, but it was superior to all the other models for this smoothing technique.

The cubic model was at the leading position using the five-year moving average (5MA) rule, and it had the highest R-square of 0.8237. This shows that the 5MA rule smoothed the series even further without affecting the efficacy of the model.

Overall, the best fit and most appropriate was the cubic regression model in the case of the gram yield for both the real, 3MA, as well as 5MA data scenarios. It had better explanatory power, always with lower prediction error, and hence was most appropriate to describe the historical trends as well as forecast future yield trends of gram in the Mirzapur region. This model, therefore, is of highest priority to agricultural researchers, planners, and policymakers, who aim to enhance yield forecasting in addition to providing sustainable pulse crop production in the district.

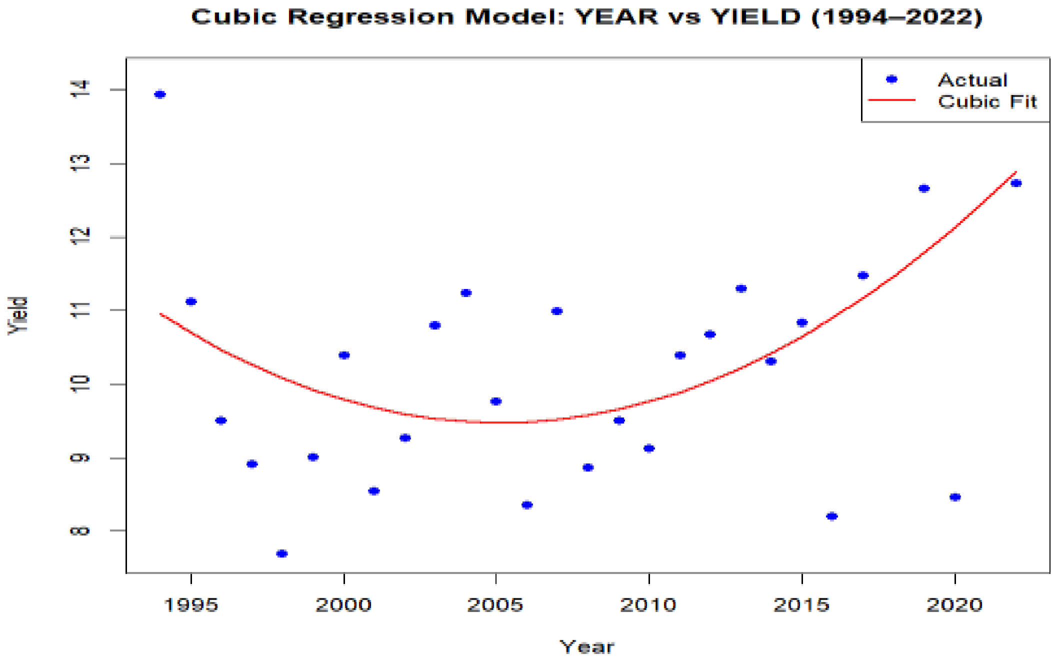

Fig 4.2.7 Fitted Trends of Yield of Gram in Mirzapur district of UP

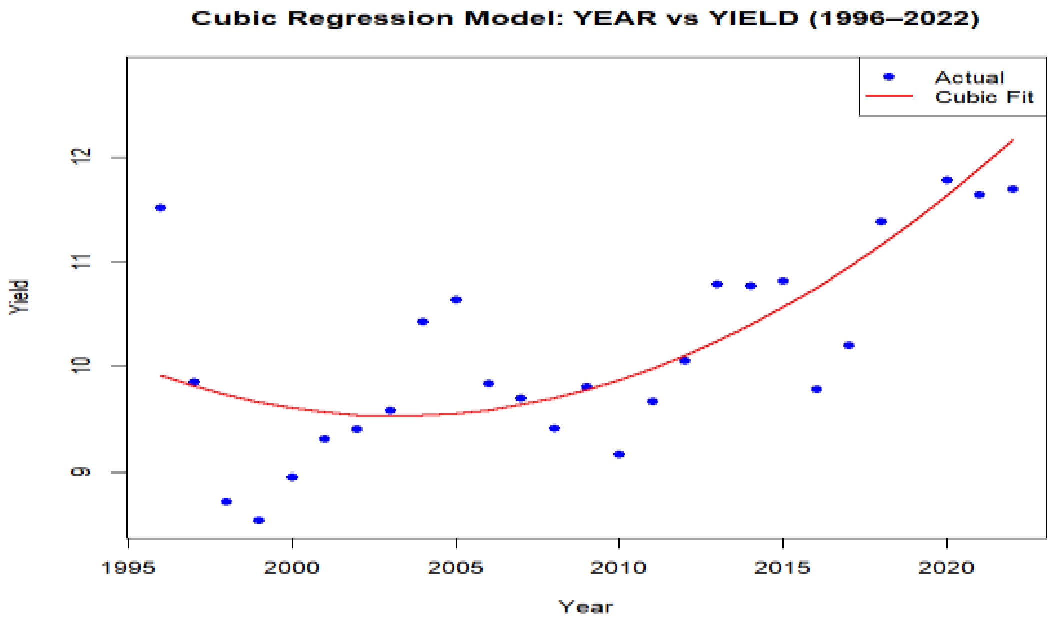

Fig 4.2.8 Fitted Trends of Yield for 3-year moving average of Gram in Mirzapur district of UP

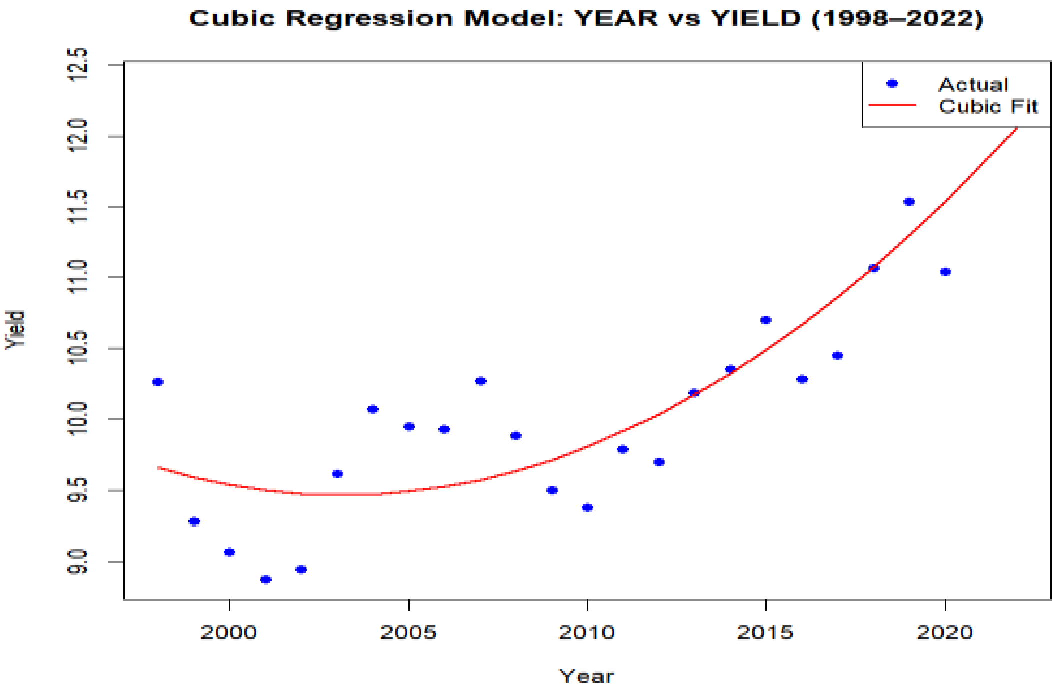

Fig 4.2.9 Fitted Trends of Yield for 5-year moving average of Gram in Mirzapur district of UP

Table 4.2.4 Model Evaluation for the area of Arhar in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	156611**	-71.27**			0.22
	3MA	182418.8**	-84.15**			0.66
	5MA	175021.2**	-80.44**			0.81
Logarithmic	Actual	1103691**	-143357**			0.22
	3MA	1300125**	-169192**			0.66
	5MA	1244024**	-161810**			0.81
Quadratic	Actual	33225483**	-33009**	8.2016**		0.38
	3MA	22394669**	-22197.2**	5.5035**		0.79
	5MA	21485471**	-21285.1**	5.274**		0.95
Cubic	Actual	**-2358213458.49**	**3539932**	**-1771.17**	**0.29**	**0.39**
	3MA	**90770499**	**-1344237.4**	**663.56**	**-0.10**	**0.80**
	5MA	**597243556.8**	**-880638.82**	**432.81**	**-0.07**	**0.95**
Power	Actual	93.93**	-11.10**			0.24
	3MA	104.92**	-12.54**			0.65
	5MA	100.54**	-11.97**			0.81
Exponential	Actual	20.59**	-0.005**			0.24
	3MA	22.03**	-0.006**			0.65
	5MA	21.45**	-0.005**			0.81

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

According to Table 4.2.4 for the actual data, the cubic model emerged as the most suitable among all models. It recorded an R-square value of 0.39, which was higher than those obtained by other competing models. This makes the cubic model more reliable overall, as it strikes a better balance between explanatory power and prediction accuracy.

When the data was smoothed using the three-year moving average (3MA), the performance of the cubic model improved significantly. It achieved a high R-square (0.80). This suggests that smoothing removed short-term fluctuations, allowing the cubic model to better capture the underlying trend in the arhar area data.

The best results were obtained with the five-year moving average (5MA). The cubic model demonstrated exceptional accuracy with an R-square of 0.956, indicating an excellent fit. These values confirm that the Cubic model is highly effective in representing long-term area trends for arhar when short-term variability is reduced.

In conclusion, the cubic regression model is the best-fitted model for analyzing the area under arhar cultivation in Mirzapur across all three data formats. Its performance is especially outstanding with smoothed datasets, particularly the five-year moving average, where it achieved the highest explanatory power and the lowest prediction errors. The consistent superiority of the cubic model highlights the presence of non-linear trends in the area data, reinforcing the suitability of higher-order polynomial models for accurate trend analysis and forecasting.

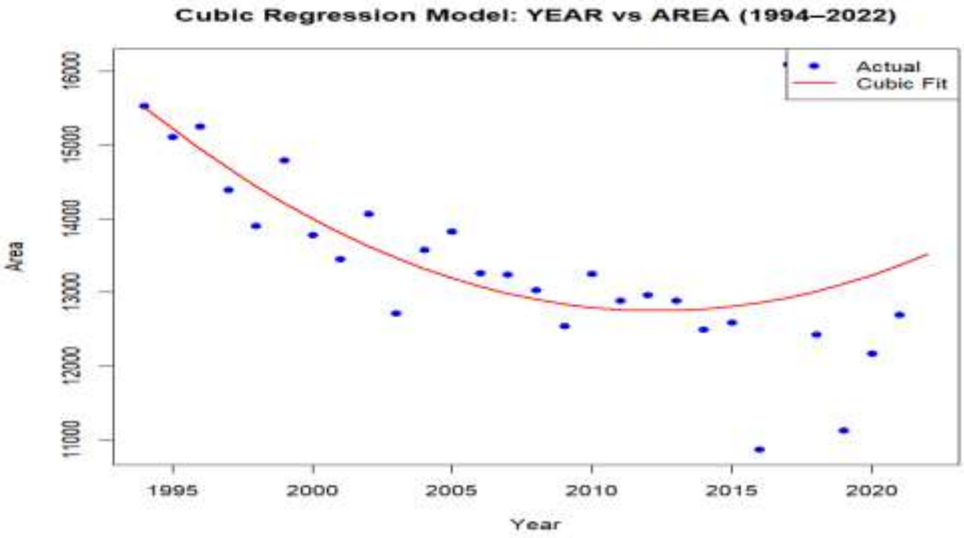

Fig 4.2.10 Fitted Trends of Area of Arhar in Mirzapur district of UP

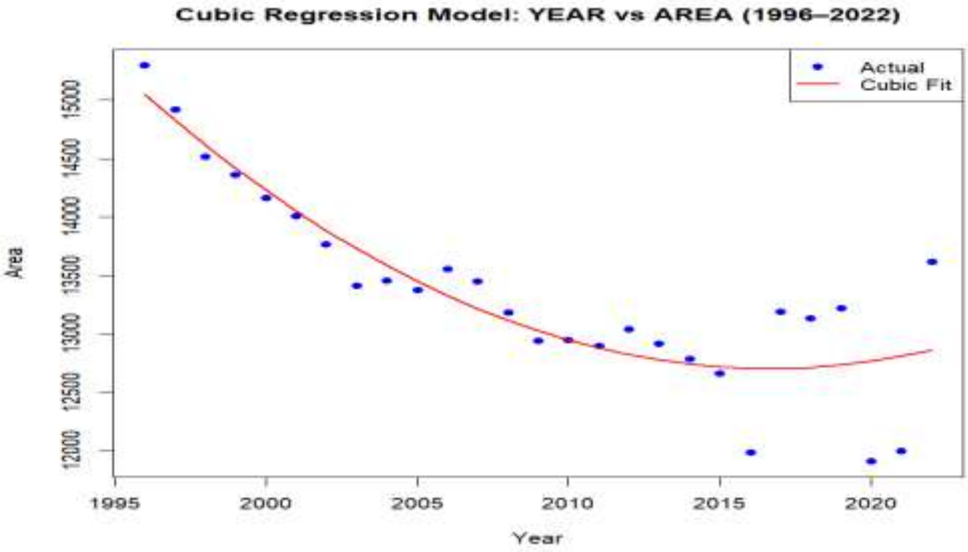

Fig 4.2.11 Fitted Trends of Area for 3-year moving average of Arhar in Mirzapur district of UP

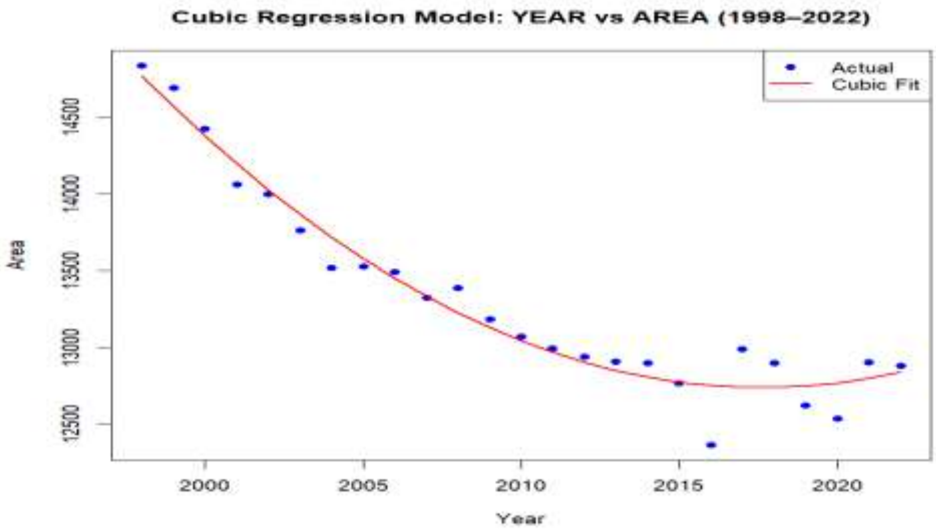

Fig 4.2.12 Fitted Trends of Area for 5-year moving average of Arhar in Mirzapur district of UP

Table 4.2.5 Model Evaluation for the production of Arhar in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	2211084	-1038.41			0.06
	3MA	2327021*	-1096.9*			0.14
	5MA	1828357	-848.9			0.11
Logarithmic	Actual	16041758	-209284			0.06
	3MA	16931743*	-2210065*			0.14
	5MA	13147745	-1712579			0.11
Quadratic	Actual	1.12**	3.65**	277.15**		0.31
	3MA	1.07**	-1068334**	265.61**		0.55
	5MA	1.23	-1225862**	304.72**		0.71
Cubic	Actual	**23581270663.69**	**-34672911.4**	**16989.89**	**-2.77**	**0.31**
	3MA	**58811295802.43**	**-87287326**	**43182.37**	**-7.12**	**0.57**
	5MA	**-609936153**	**9718055.99**	**-5140.04**	**0.90**	**0.71**
Power	Actual	132.57	-15.89			0.04
	3MA	137.83*	-16.58			0.11
	5MA	109.06	-12.81			0.08
Exponential	Actual	27.53**	-0.007			0.04
	3MA	28.23**	-0.008			0.11
	5MA	24.44**	-0.006			0.08

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.5 shows that, by using the examination of actual production data, it was found that the cubic model was the most fitted. It was displaying a comparatively good R-square measure value of 0.31, which was, although moderate, but highest of all under real conditions.

With the data set smoothed by using the 3-Year Moving Average (3MA) method to remove the short-run fluctuation and forecast intermediate trends, the cubic model performed better. It achieved a high R-square of 0.57, indicating good goodness of fit. This means that where medium-term smoothing prevails, the cubic model captures underlying trends in Arhar output more accurately than competing models. quadratic, interestingly enough, also performed better under 3MA R-square (0.55), though behind on goodness-of-fit as well as error rankings.

The best cubic model fit was obtained in the 5-Year Moving Average (5MA) setting. This setting eliminates short- and medium-term outliers to address long trends. In this setting, the cubic model obtained the highest R-square value of 0.71, which is a very strong model fit. This proves the cubic model is superior, and it performs very well even under conditions of long-term smoothing.

Lastly, the cubic model of regression is the most reliable and accurate in evaluating the yield of arhar across all three sets of data. Given its capacity to accurately predict nonlinear trends with minimal margin of error, it can be used not only for short-range forecasting purposes but also for long-range farm planning in the Mirzapur district. Therefore, the cubic model is proposed to be used in the future for predicting trends, estimating yields, and formulating strategies regarding pulse crop growth and development within the region.

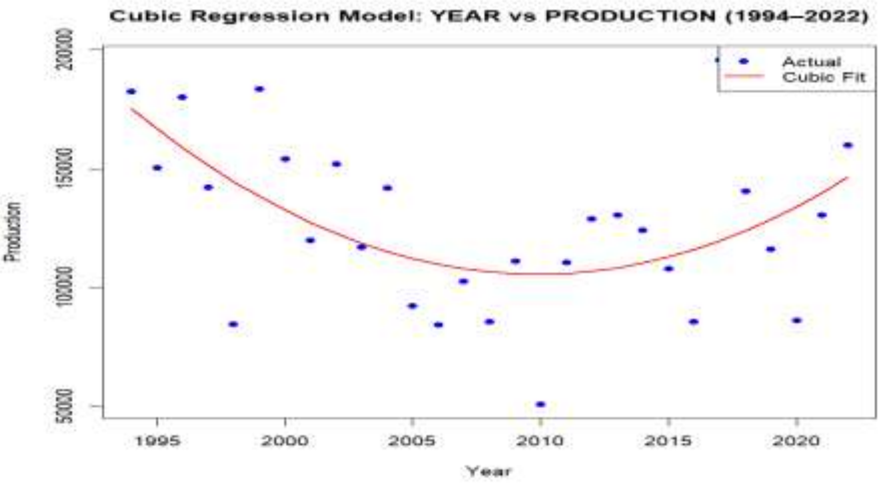

Fig 4.2.13 Fitted Trends of Production of Arhar in Mirzapur district of UP

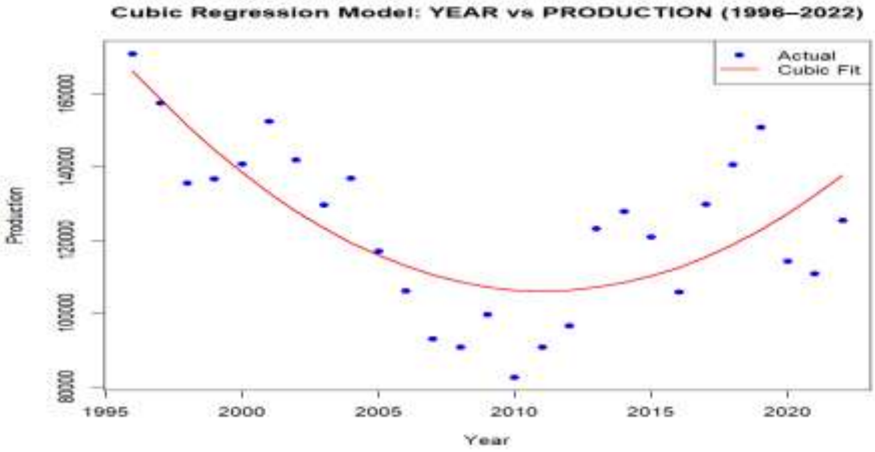

Fig 4.2.14 Fitted Trends of Production for 3-year moving average of Arhar in Mirzapur district of UP

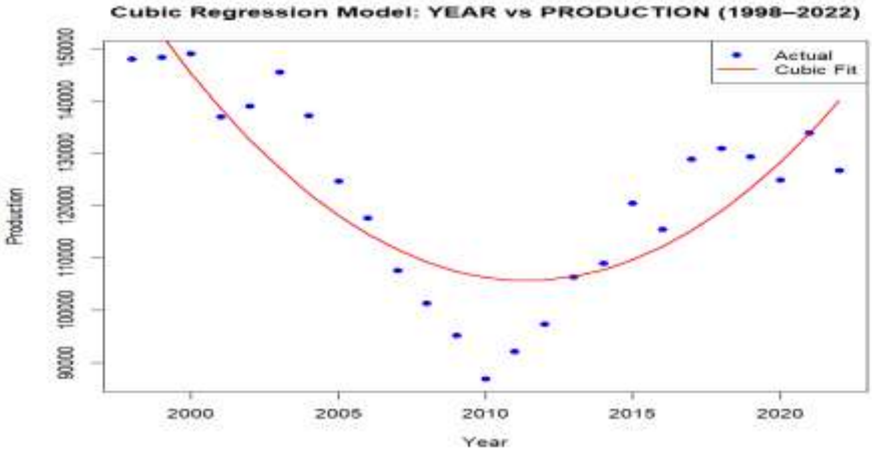

Fig 4.2.15 Fitted Trends of Production for 5-year moving average of Arhar in Mirzapur district of UP

Table 4.2.6 Model Evaluation for the yield of Arhar in Mirzapur district of U.P.

		Parameter				Criteria
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	59.38	-0.02			0.01
	3MA	52.43	-0.02			0.01
	5MA	23.05	-0.006			0.001
Logarithmic	Actual	393.41	-50.51			0.01
	3MA	341.02	-43.63			0.015
	5MA	118.06	-14.32			0.002
Quadratic	Actual	57253.54**	-56.99*	0.01*		0.19
	3MA	61666.14**	-61.36**	0.01**		0.39
	5MA	74234.17**	-73.84**	0.018**		0.57
Cubic	Actual	**2698701**	**-4003.46**	**1.97**	**-0.0003**	**0.20**
	3MA	**3020868.63**	**-4480.35**	**2.21**	**-0.0003**	**0.40**
	5MA	**-1517442.83**	**2301.82**	**-1.16**	**0.0001**	**0.57**
Power	Actual	38.63	-4.79			0.006
	3MA	36.26	-4.47			0.012
	5MA	13.23	-1.45			0.001
Exponential	Actual	6.94	-0.002			0.005
	3MA	6.63	-0.002			0.012
	5MA	3.60	-0.0007			0.001

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

According to Table 4.2.6, for actual yield data, the cubic model was the most appropriate among all models. It provided an R-square of 0.20, which was larger than those from less complicated models.

As the data was smoothened by the use of the 3-Year Moving Average (3MA) technique to remove short-run fluctuations, the cubic model significantly improved its performance. It achieved an R-square of 0.40. The results reflect that the model becomes stable and better-fitted when medium-run trends are filtered. Though the quadratic model also fared extremely well under 3MA R-square (0.39).

The cubic model scored highest in the 5-Year Moving Average (5MA) scenario. Under this smoothing technique, the cubic model achieved the highest R-square value (0.57). These values reflect the model's better capacity to learn structural yield changes over time with very good predictability. The quadratic model, though nearly competing with the same R-square (0.57), reaffirms the superiority of the cubic model even with long-term data.

Lastly, the cubic regression model always became the best and significant model in explaining the yield of arhar in Mirzapur in all three paradigms of analysis, actual data, 3MA, and 5MA. It possessed both the highest explanatory power and the lowest prediction errors, and hence it became most suitable for forecasting the yield in the short run as well as the long run. Its ability to accommodate different amounts of smoothing of data gives credence to its usefulness in planning agriculture, forecasting crop yield, and policy formulation. Similarly, the cubic model is highly suggested for reuse in future studies and local agricultural decision-making.

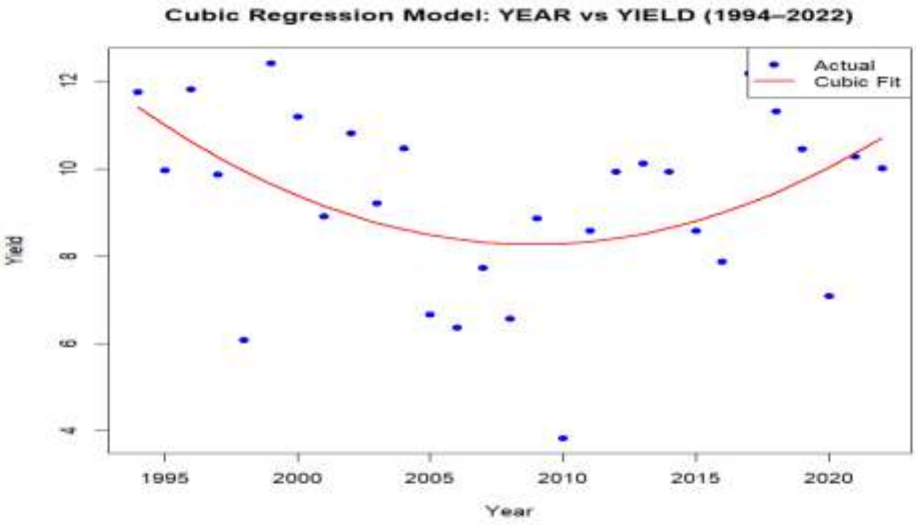

Fig 4.2.16 Fitted Trends of Yield of Arhar in Mirzapur district of UP

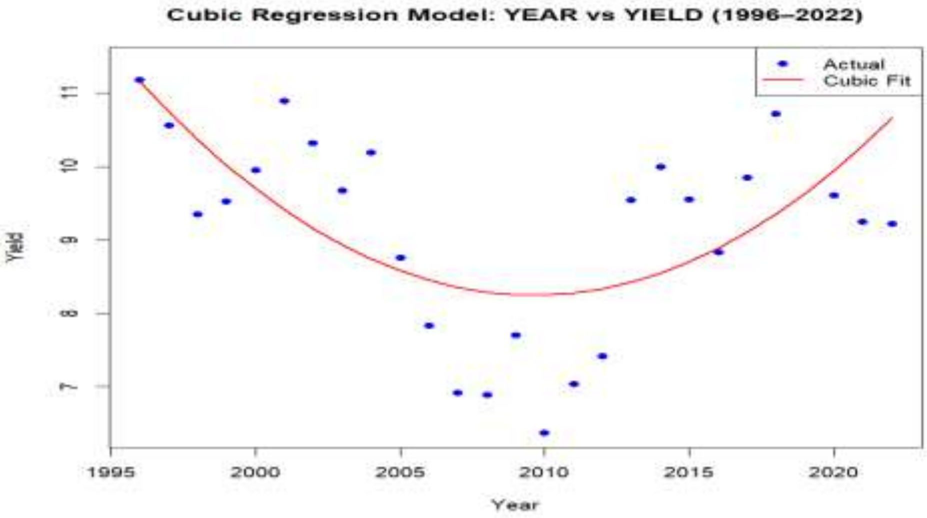

Fig 4.2.17 Fitted Trends of Yield for 3-year moving average of Arhar in Mirzapur district of UP

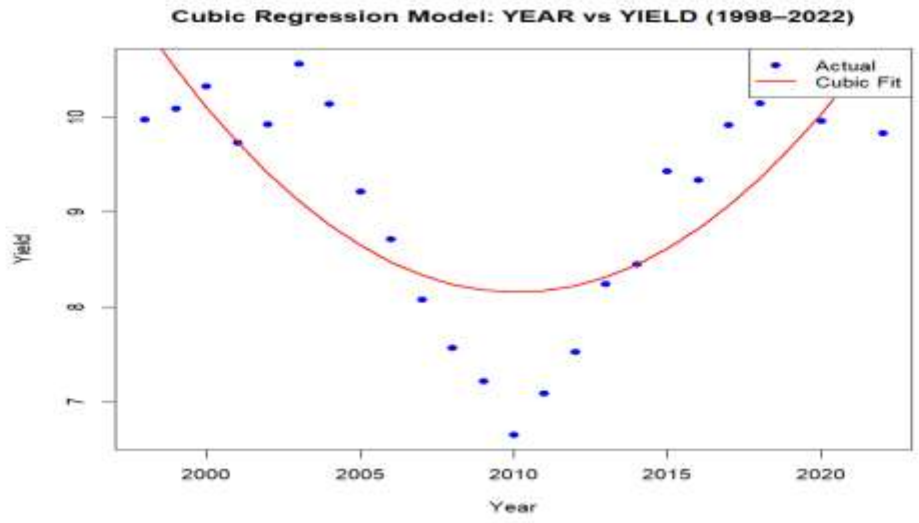

Fig 4.2.18 Fitted Trends of Yield for 5-year moving average of Arhar in Mirzapur district of UP

Table 4.2.7 Model Evaluation for the area of Lentil in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	11214.1	-2.9231			0.0009
	3MA	19047.4	-6.8227			0.006
	5MA	38836.52	-16.671			0.04
Logarithmic	Actual	49785.89	-5843.8			0.0009
	3MA	109305	-13670			0.006
	5MA	259720	-33447			0.04
Quadratic	Actual	-3660416	3654.14	-0.91		0.006
	3MA	-6072719	6057.74	-1.50		0.02
	5MA	-1.2	12148.93	-3.02		0.10
Cubic	Actual	**-658073167**	**9830160.22**	**-4894.63**	**0.81**	**0.22**
	3MA	**-9.6****	**1.4****	**-71107.8****	**11.79****	**0.45**
	5MA	**-1.3****	**1.98****	**-98587.4****	**16.34****	**0.76**
Power	Actual	23.12	-1.91			0.003
	3MA	23.12	-1.91			0.003
	5MA	31.31	-2.98			0.008
Exponential	Actual	10.49	-0.0001			0.003
	3MA	11.57	-0.001			0.008
	5MA	15.04*	-0.003			0.04

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

By Table 4.2.7, for examination of the Lentil area actual data, the cubic model worked best among any of the models tried. It had a Maximum R-square of 0.22 across all models. Although the comparatively lower R-square in the cubic model in the real data scenario, it was producing the best fit, which depicts a more efficient predictive power compared to others.

The performance of the cubic model was considerably enhanced by utilizing a 3-Year Moving Average (3MA). This was the smoothing technique that reduced volatility in the short run and improved model estimation. In this data set, the cubic model recorded an enormous jump in R-square (0.45). These values assured that the cubic model explained medium-term variances better and yielded a better fit than other models. Even though the quadratic model improved somewhat, with too R-square (0.02), it could not match the accuracy of the cubic model based on either R-square or estimates of error.

The model worked best when used with 5-Year Moving Average (5MA) data, which filters out short- and medium-term anomalies and captures long-term trends in the region under Lentil cultivation. In such a scenario, the cubic model provided the highest R-square value of 0.76, meaning an extremely high correlation between estimated and observed values, placing the cubic model as the most statistically valid and overall best of all the models.

Finally, the cubic model proved to be the most accurate, consistent, and strong model to predict the area under lentil production in Mirzapur district. It has higher performance in R-square. The model is thus suggested for subsequent trend projections, planning in space, and formulating agricultural policy for the regional development of the lentil crop in the region.

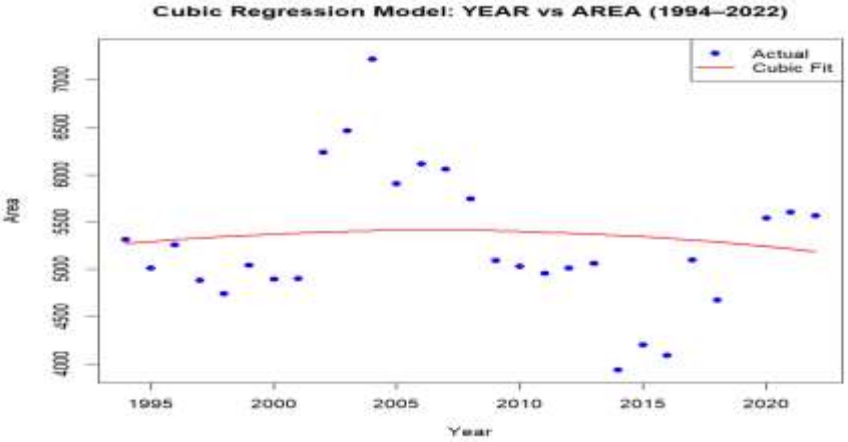

Fig 4.2.19 Fitted Trends of Area of Lentil in Mirzapur district of UP

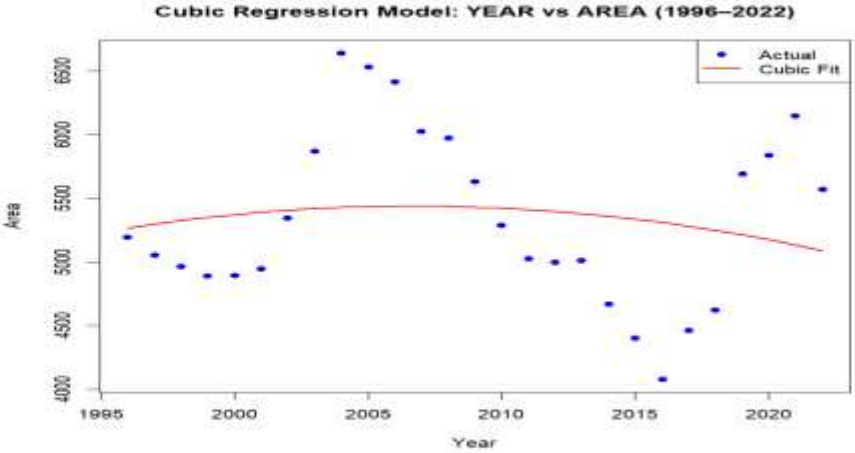

Fig 4.2.20 Fitted Trends of Area for 3-year moving average of Lentil in Mirzapur district of UP

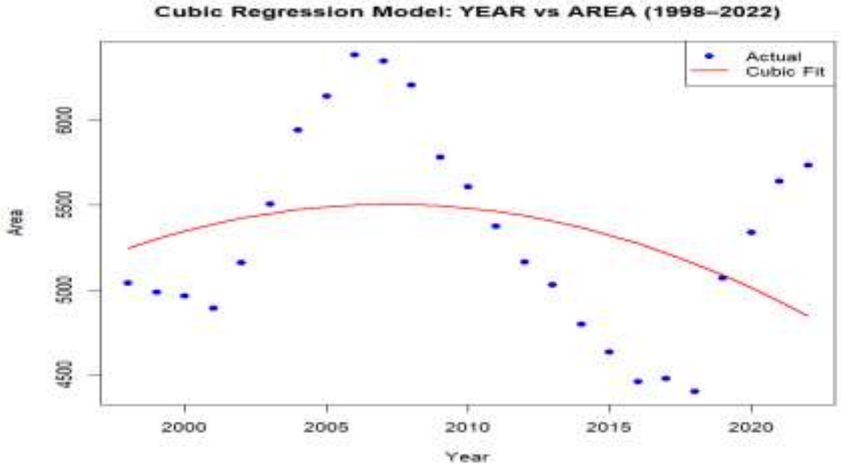

Fig 4.2.21 Fitted Trends of Area for 5-year moving average of Lentil in Mirzapur district of UP

Table 4.2.8 Model Evaluation for the production of Lentil in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	-616913	328.18			0.06
	3MA	-55178	295.51			0.09
	5MA	-394369	217.04			0.07
Logarithmic	Actual	-4968698	658890.2			0.06
	3MA	-4474095.80	593787			0.09
	5MA	-3277217.09	436388			0.07
Quadratic	Actual	14485356	-14714.2	3.75461		0.06
	3MA	-20115437.4	19771.81	-4.847		0.10
	5MA	-24183510.6	23888.14	-5.88		0.07
Cubic	Actual	**-6.4**	**95985267**	**-47656.1**	**7.91**	**0.18**
	3MA	**-9567667201**	**142864389.30**	**-71107.8**	**11.79**	**0.45**
	5MA	**-1.32****	**1.98****	**-98587.4****	**16.34****	**0.76**
Power	Actual	-88.01	12.96			0.05
	3MA	-92.77	13.59			0.09
	5MA	-68.52	10.40			0.07
Exponential	Actual	-2.35	0.006			0.05
	3MA	-2.96	0.006			0.0
	5MA	0.23	0.005			0.07

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

From Table 4.2.8 for actual production data, the cubic model was once more the best-fit model of all considered. It produced the maximum R-square value of 0.18, which shows a relatively higher explanatory power than linear R-square (0.06) and logarithmic R-square (0.06) models, both of which explained a very negligible part of the trend.

Model performance improved in general by the use of 3-Year Moving Average (3MA) smoothing, but especially that of the cubic model, whose R-square measure of 0.45, which shows that even though 3MA did not have a major impact on the fit statistics within cubic, it stabilized the parameter estimates and maintained the predictability of the model.

There was a stunning improvement in model performance by the 5-Year Moving Average (5MA). On smoothed data for the latter, the cubic model decimated all others hands down with a significantly better R-square of 0.76 to assert that the cubic model is much more efficient and precise when applied to long-term smoothed data.

From the above analysis, it is evident that the cubic regression model is the most stable, accurate, and significant model to explain the patterns of production of lentil in Mirzapur district for all three datasets: actual, 3-Year MA, and 5-Year MA. Being able to handle varying levels of data smoothing has turned it into an effective instrument for yield forecasting, agricultural research, and policy making. Hence, the cubic model is suggested for future projections, long-term strategic resource planning, and long-term agriculture development plans for growing Lentils in this region.

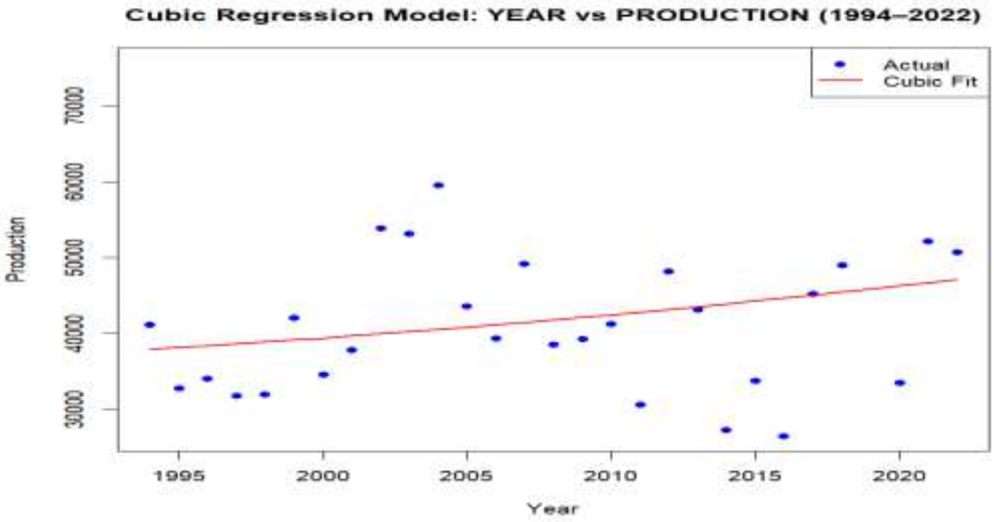

Fig 4.2.22 Fitted Trends of Production of Lentil in Mirzapur district of UP

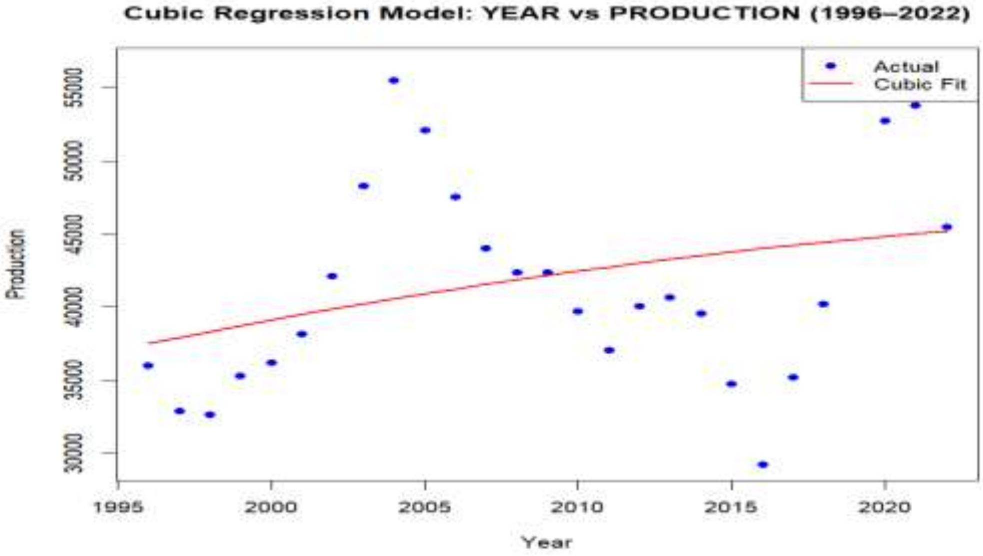

Fig 4.2.23 Fitted Trends of Production for 3-year moving average of Lentil in Mirzapur district of UP

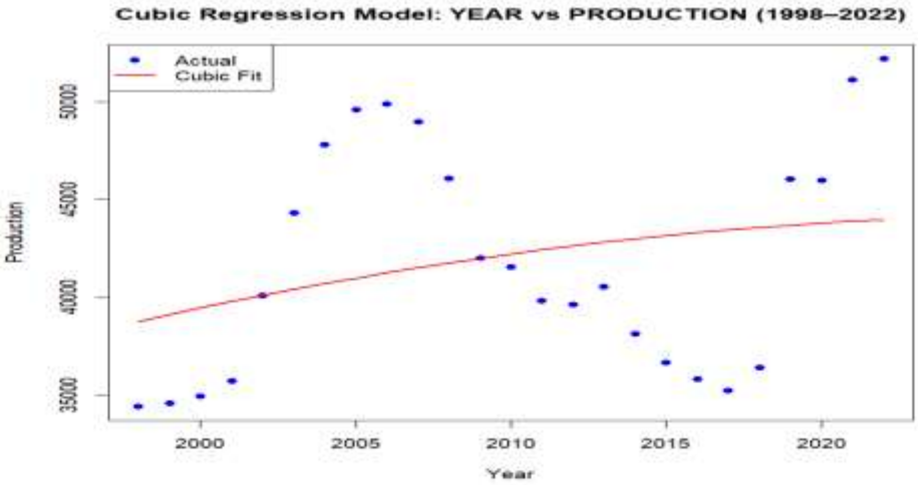

Fig 4.2.24 Fitted Trends of Production for 5-year moving average of Lentil in Mirzapur district of UP

Table 4.2.9 Model Evaluation for the yield of Lentil in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	-118.82*	0.06**			0.19
	3MA	-117.44**	0.06**			0.44
	5MA	-118.10**	0.0**			0.61
Logarithmic	Actual	-954.97	126.60			0.19
	3MA	-944.54**	125.21**			0.44
	5MA	-649.52**	125.86**			0.61
Quadratic	Actual	5958.76	-5.99	0.001		0.19
	3MA	1951.89	-1.99	0.0005		0.44
	5MA	9741.52	-9.74	0.002		0.65
Cubic	Actual	**-2292444**	**3427.94**	**-1.70**	**0.0002**	**0.20**
	3MA	**-3705052**	**5533.69**	**-2.75**	**0.0004**	**0.50**
	5MA	**-6728705****	**10047.8****	**-5.001****	**0.0008****	**0.82**
Power	Actual	-111.13*	14.88*			0.16
	3MA	-119.3**	15.95**			0.45
	5MA	-119.3**	15.95**			0.61
Exponential	Actual	-12.84	0.0074**			0.16
	3MA	-13.90**	0.0079**			0.45
	5MA	-13.90**	0.0079**			0.61

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

According to Table 4.2.9, for actual observations, the cubic model performed relatively better than other models with an R-square of 0.20. Although they were moderate in explanatory power, these were the best among all compared models for actual observation. Thus, for raw yield data, the cubic model appeared relatively more appropriate in accounting for variability.

With the aid of the 3-Year Moving Average (3MA), the majority of the models displayed an improved measure of performance, especially the cubic regression model. The R-square of the cubic model was 0.50, indicating a remarkable change in the explanatory capacity of the model for yield fluctuation. It shows that 3MA smoothing had a stabilizing influence and predictive effect on the model by reducing short-run volatility.

The most striking achievement was, however, obtained on the smoothed data with the 5-Year Moving Average (5MA). Here, the cubic model emerged as the best fit among all statistical models. The R-square shot up to 0.82, which reflects a really strong and solid correlation between the modeled variables and lentil yield. Improved performance under 5MA conditions supports model strength in trend detection of long-term without year-to-year variability.

Under all three model scenarios, the cubic model found a better fit and predictability of Mirzapur district lentil yield. Particularly under 5MA, its performance was remarkable with R-square (0.82) reasserting itself as the most appropriate and credible model to predict agricultural yield in this case. Its appropriateness is that it measures a nonlinear pattern of growth and yield change over time, and thus qualifies it to be the model of preference for future forecasting and policy formulation for lentil production.

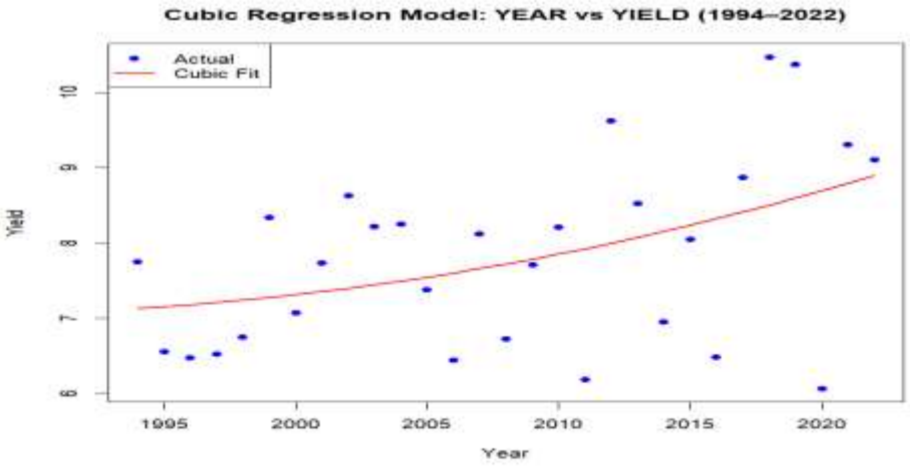

Fig 4.2.25 Fitted Trends of Yield of Lentil in Mirzapur district of UP

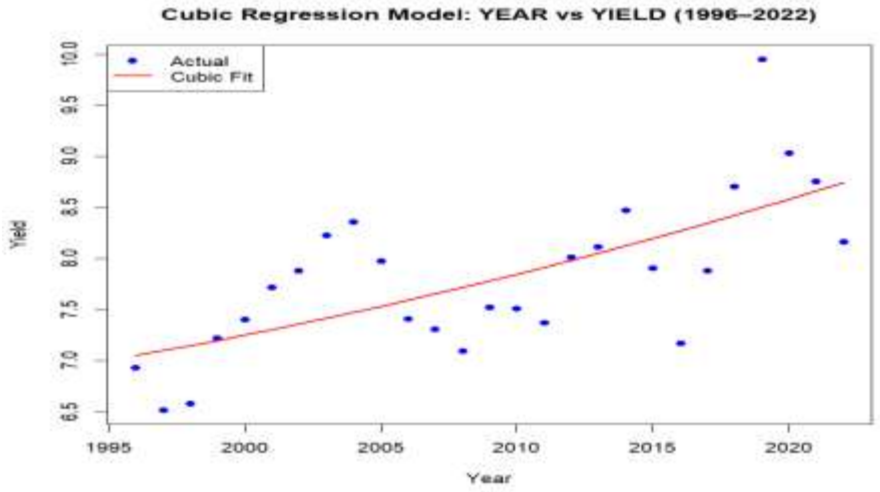

Fig 4.2.26 Fitted Trends of Yield for 3-year moving average of Lentil in Mirzapur district of UP

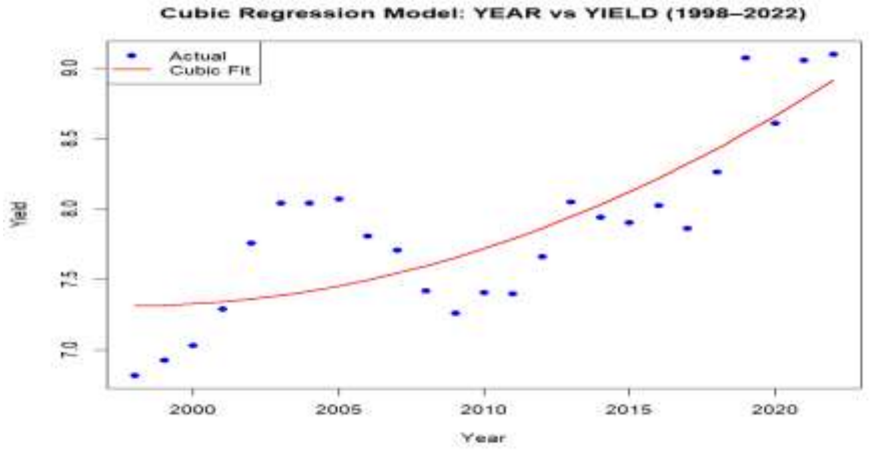

Fig 4.2.27 Fitted Trends of Yield for 5-year moving average of Lentil in Mirzapur district of UP

Table 4.2.10 Model Evaluation for the area of Urad in Mirzapur district of U.P.

		Parameter				Criteria
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	18638.57**	-8.88**			0.34
	3MA	19824.8**	-9.46**			0.47
	5MA	25214.4**	-12.145**			0.71
Logarithmic	Actual	136504.4**	-17844.2**			0.34
	3MA	145546.5**	-19.32**			0.47
	5MA	186567.6**	-24424**			0.71
Quadratic	Actual	1027296	-1013.64	0.25		0.35
	3MA	1439289	-1422.6	0.35		0.50
	5MA	2204558*	-2180.68*	0.53*		0.77
Cubic	Actual	**-9.4****	**140676****	**-700.84****	**0.11****	**0.53**
	3MA	**-1.4****	**2030570****	**-1011.1****	**0.16****	**0.83**
	5MA	**-1.1**	**1671506****	**-832.14****	**0.13****	**0.92**
Power	Actual	16069.41**	-742.92**			0.35
	3MA	182.22**	-23.08**			0.48
	5MA	233.93**	-29.87**			0.72
Exponential	Actual	28.36**	-0.01**			0.35
	3MA	29.74**	-0.01**			0.48
	5MA	36.54**	-0.01**			0.72

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.10 shows that for actual data, the cubic model was the best among all the models attempted. It recorded a maximum R-square value of 0.53 with moderate but better fitness than other models like linear R-square (0.34), logarithmic (0.34), and quadratic (0.35).

After smoothing with the 3-Year Moving Average (3MA), all models were good. The cubic model was best with a very high R-square value of 0.83. These gains arise from removing the short-run volatility, hence allowing the underlying trend to emerge more clearly.

5-Year Moving Average (5MA) also enhanced model performance. The cubic model performed the best of all with excellent statistics: R-square of 0.92. The indicators reveal the cubic model's better capability of representing the long-term trend and volatility in the Urad cultivation area with fewer errors. None of the other models were estimated as close in total fit and accuracy, yet the quadratic model under 5MA was also estimated with a good R-square (0.77).

For each of the three datasets, actual, 3MA, and 5MA, the cubic model was consistently the best and most accurate model in the description and prediction of the Urad cropped area of Mirzapur district. The model was more accurate and data smoothening closer to and better under 5MA with R-square (0.92). These results validate the robustness of the Cubic model and make it the optimal choice for policy modeling, projection of Urad crop area into the future, and planning in the region.

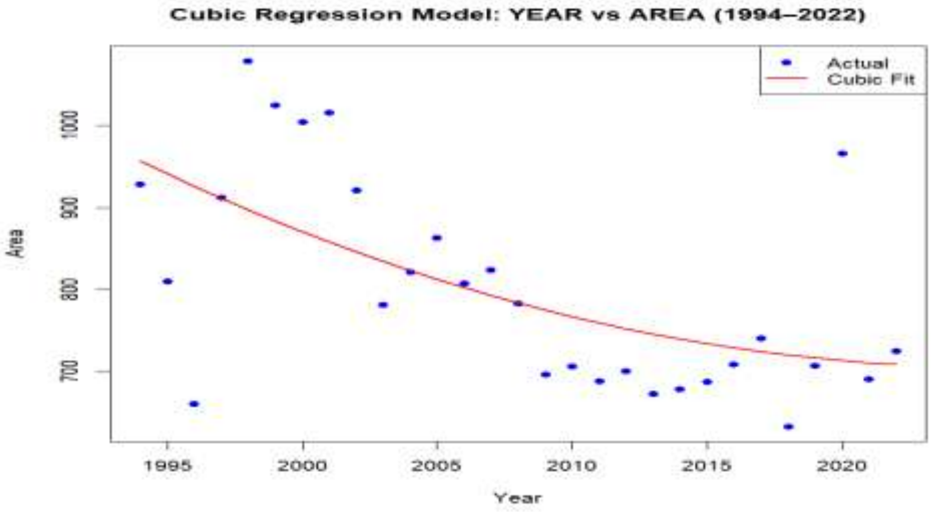

Fig 4.2.28 Fitted Trends of Area of Urad in Mirzapur district of UP

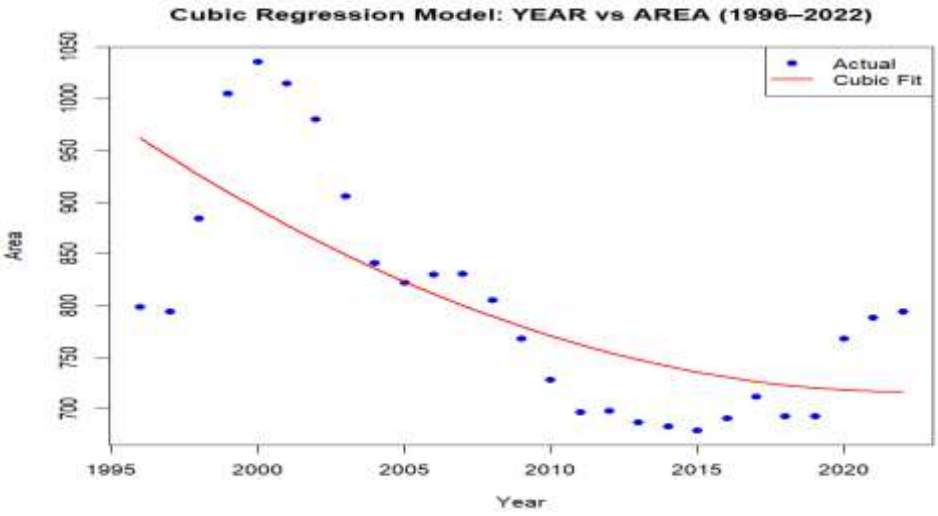

Fig 4.2.29 Fitted Trends of Area for 3-year moving average of Urad in Mirzapur district of UP

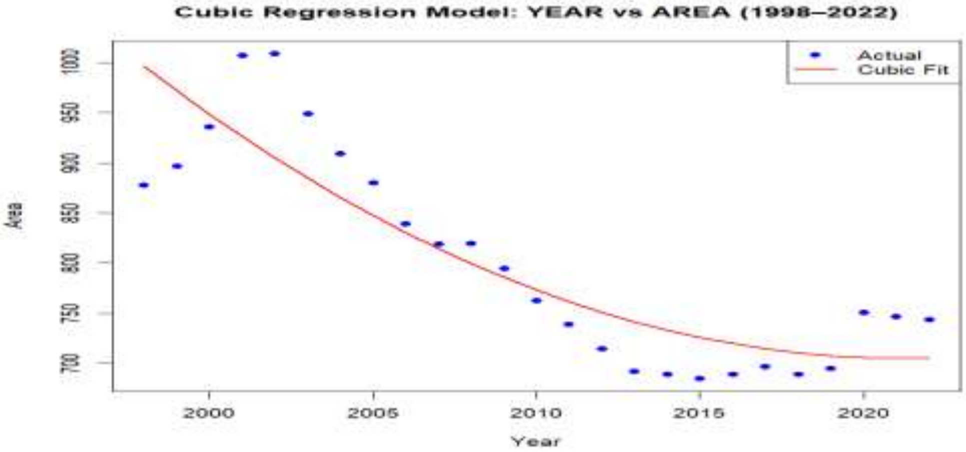

Fig 4.2.30 Fitted Trends of Area for 5-year moving average of Urad in Mirzapur district of UP

Table 4.2.11 Model Evaluation for the production of Urad in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	-61844.7	33.06			0.04
	3MA	-76759.1	40.46			0.13
	5MA	-45177.1	24.69			0.08
Logarithmic	Actual	-498756	66181.71			0.04
	3MA	-498756	66181.71			0.04
	5MA	-611895	81051.59			0.13
Quadratic	Actual	30287921*	-30196.3*	7.52*		0.16
	3MA	4.**	-39820**	9.92**		0.51
	5MA	-42005.4**	-42005.4**	10.45**		0.70
Cubic	Actual	**-7.3**	**1102604**	**-556.62**	**0.09**	**0.16**
	3MA	**-3.8**	**5695852**	**-2845.09**	**0.47**	**0.55**
	5MA	**7.4**	**-88628.4**	**33.65**	**-0.003**	**0.70**
Power	Actual	-74.92	10.95			0.03
	3MA	-109.01	15.43			0.10
	5MA	-70.14	10.32			0.07
Exponential	Actual	-2.61	0.005			0.03
	3MA	-7.08	0.007			0.10
	5MA	-1.98	0.005			0.07

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.11 for the actual production data test proves that all models have low explanatory power since their R-squares are below 0.20. The cubic model had the highest value for R-square (0.16), and the Quadratic model had the value of R-square (0.16).

Introduction of the 3MA approach significantly improved model performance. The cubic model had the highest R-square (0.55). This indicates that the cubic model can capture the trend more and reduce lower prediction errors in the event that smoothing is taken into account. quadratic model closely followed by R-square (0.51), which estimated the dominance of smoothing methods.

For 5MA, the model performance continued to improve. cubic and quadratic models both provided the highest R-square of 0.70, indicating higher accuracy and goodness of fit for the trend.

The cubic model best fits under 3MA with a maximum goodness of fit R-square (0.55) and minimum prediction errors. For Quadratic and Cubic models within 5MA, they also describe equivalent trends in production R-square (0.70). Smoothing techniques (3MA and 5MA) play an important role in model validity by reducing error indicators and improving better fit. cubic (5MA) is suited best for planning and policy of Mirzapur's Urad production.

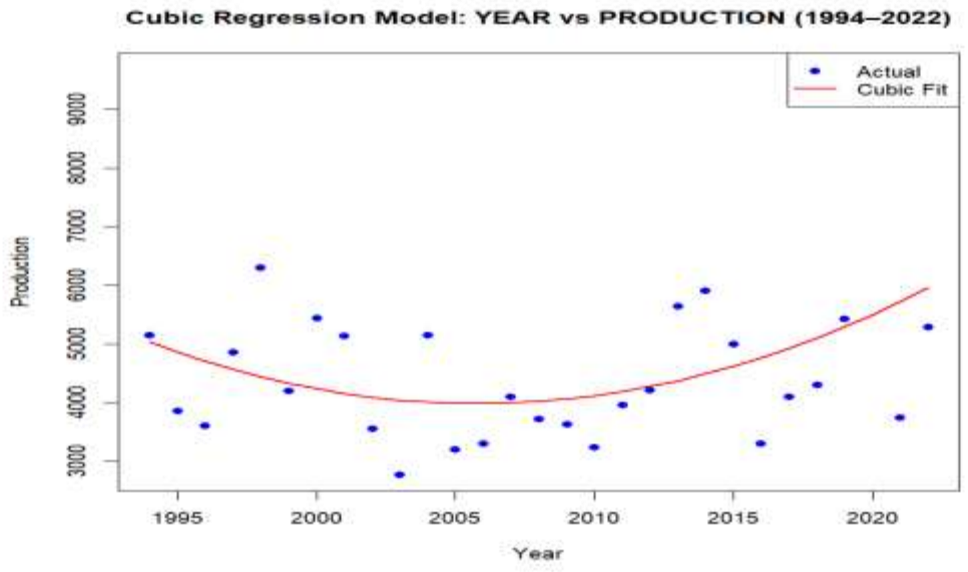

Fig 4.2.31 Fitted Trends of Production of Urad in Mirzapur district of UP

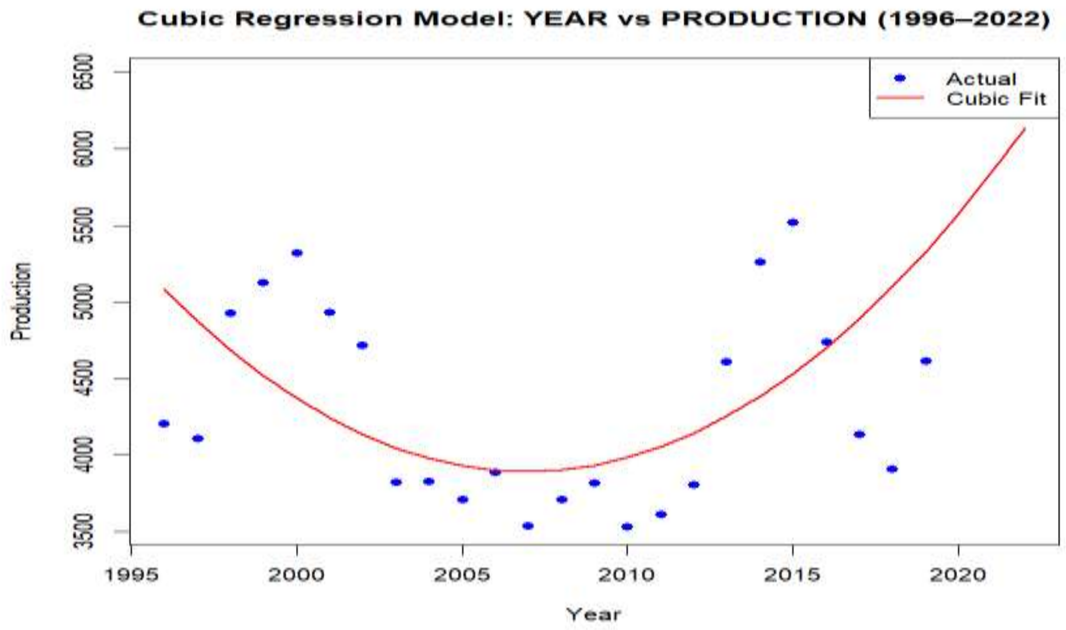

Fig 4.2.32 Fitted Trends of Production for 3-year moving average of Urad in Mirzapur district of UP

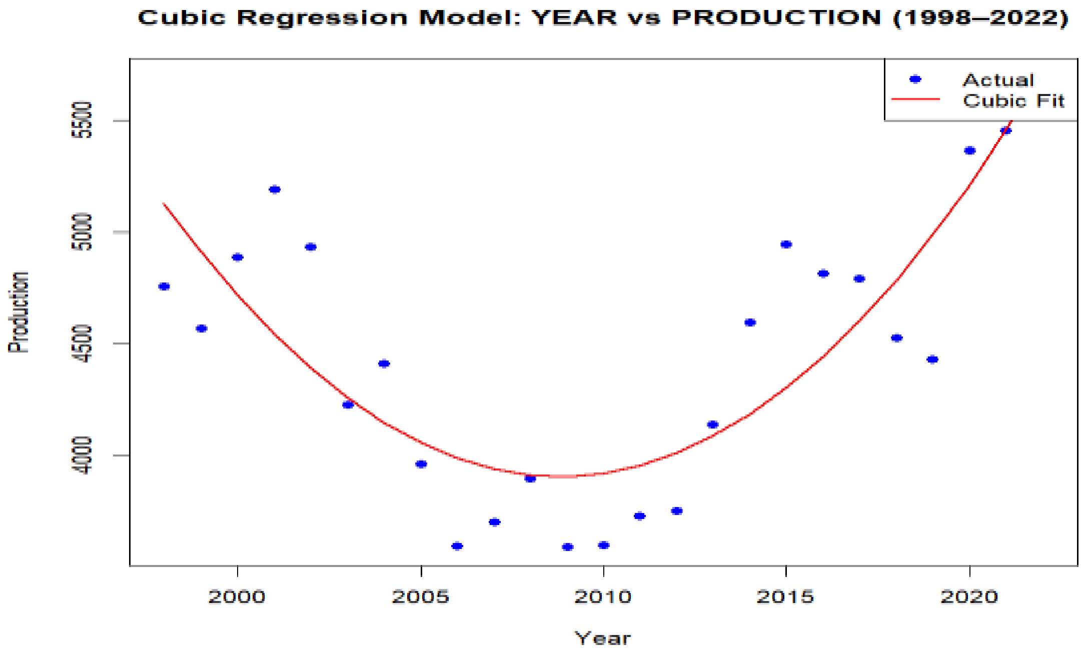

Fig 4.2.33 Fitted Trends of Production for 5-year moving average of Urad in Mirzapur district of UP

Table 4.2.12 Model Evaluation for the yield of Urad in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	-197.71**	0.10**			0.30
	3MA	-61844.7	33.06			0.04
	5MA	-224.80**	0.11**			0.62
Logarithmic	Actual	-1539.98	203.25			0.30
	3MA	-1724.52**	227.50**			0.51
	5MA	-1748.71**	230.26**			0.62
Quadratic	Actual	27877.7**	-27.86	0.006		0.38
	3MA	35865.7**	-35.81**	0.009**		0.67
	5MA	35475.8**	-35.40**	0.008**		0.78
Cubic	Actual	**6050813**	**-9026.46**	**4.48**	**-0.0007**	**0.43**
	3MA	**5865494**	**-8741.24**	**4.34**	**0.0007**	**0.71**
	5MA	**8837944****	**-13173.6****	**6.54****	**-0.001****	**0.87**
Power	Actual	-246.61**	32.65**			0.28
	3MA	-283.16**	37.45**			0.50
	5MA	-297.59**	39.35**			0.60
Exponential	Actual	-30.97	0.01			0.28
	3MA	-35.77**	0.018**			0.50
	5MA	-37.67**	0.01**			0.60

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.12 shows that for actual data, the cubic model was better than the other models. It showed the highest value of R-square as 0.43, representing the moderate level of variation.

The three-year moving average data condition resulted in a vast improvement in the performance of all models, especially that of the cubic model. The cubic model R-square was 0.71. This is to say that smoothing data with a 3MA filter enabled the model to capture the trend more accurately, smoothing the shocks from short-run fluctuations and anomalies.

When smoothened with the five-year moving average (5MA) as well, the cubic model worked best once more. It recorded the highest ever R-square (0.87), which indicated extremely high predictability and the least deviation from actual yield values. This better performance is enhancing the robustness of the cubic model of prediction of Urad long-term yields, particularly following noise smoothing.

Briefly, the cubic is the best-performing model of Urad yield analysis for the whole collection of data types of Mirzapur district. It performs best even when actual data are employed, but is extremely accurate when employing 3MA, and best of all when employing 5MA. These results show the complex and non-linear trend nature of Urad yield that can be identified and modeled by the higher-order cubic model. Hence, the cubic model would be most useful in predicting yield and informing policy actions for Urad production in the area.

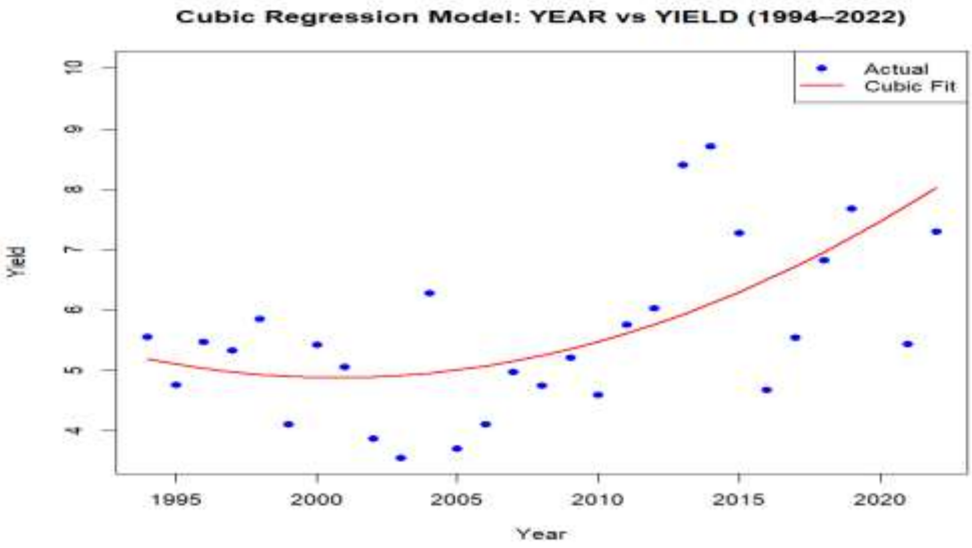

Fig 4.2.34 Fitted Trends of Yield of Urad in Mirzapur district of UP

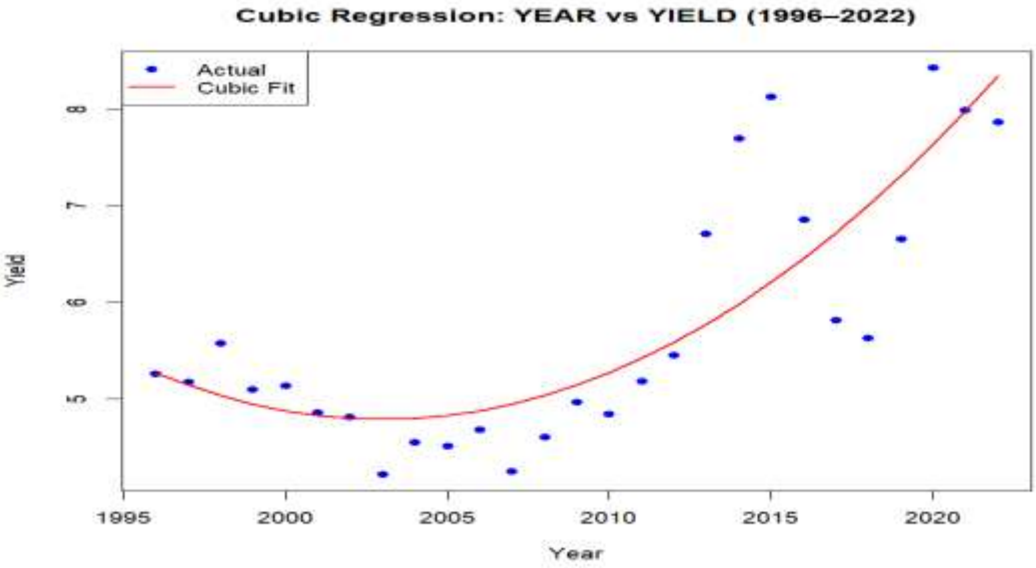

Fig 4.2.35 Fitted Trends of Yield for 3-year moving average of Urad in Mirzapur district of UP

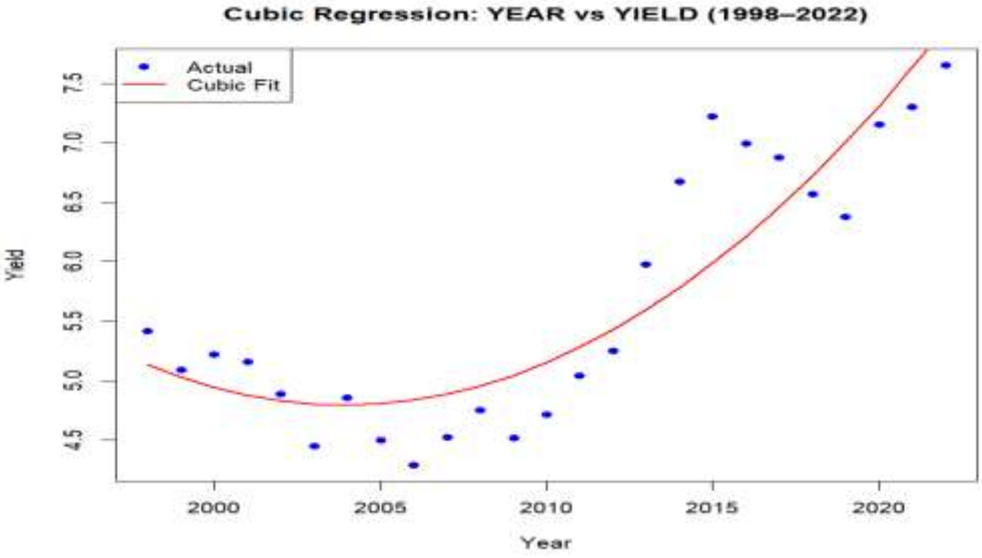

Fig 4.2.36 Fitted Trends of Yield for 5-year moving average of Urad in Mirzapur district of UP

Table 4.2.13 Model Evaluation for the area of Pea in Mirzapur district of U.P.

		Parameter				Criteria
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	48664.34	-22.26			0.06
	3MA	61772.41	-28.75			0.11
	5MA	83015.8**	-39.28*			0.21
Logarithmic	Actual	34276.5	-44550.4			0.06
	3MA	442323.1	-57631.6			0.11
	5MA	603849.6*	-78859*			0.21
Quadratic	Actual	-2.2**	21683.51**	-5.40**		0.26
	3MA	-2.1*	21090.5*	-5.25*		0.29
	5MA	-1.9*	19146.38*			0.34
Cubic	Actual	**-7.6****	**11305798****	**-5625.04****	**0.93****	**0.59**
	3MA	**-1.02****	**15232037****	**-7576.73****	**1.25****	**0.76**
	5MA	**-1.3**	**1.9**	**-9529**	**1.57**	**0.90**
Power	Actual	93.44	-11.2			0.06
	3MA	113.65	-13.85			0.10
	5MA	153.87**	-19.13*			0.20
Exponential	Actual	19.50**	-0.005			0.06
	3MA	22.16**	-0.006			0.10
	5MA	27.45**	-0.009*			0.20

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

By Table 4.2.13 for actual data, the cubic model was the most appropriate model fitting the trend for the pea growth example. It provided the highest R-square value (0.59) among all models attempted with actual values. This means that the cubic model is a more accurate one to describe real area data's non-linear variability and points of inflexion.

With 3-Year Moving Average (3MA) data, model performance also became much better following the removal of the volatility in the short run. The cubic model once again produced the best fit with R-square (0.76), indicating that it had greater explanatory power.

For 5-Year Moving Average (5MA) data, the cubic model showed the best fit. It possessed an extremely high R-square of 0.90, the highest for any of the data types. The greater model precision with 5MA also captures the less spread character of the data, which attenuates the year-to-year volatility and is an advantage for model estimation.

Finally, for all the authentic, 3MA, and 5MA data sets, the cubic regression model was the best model to analyze the area of pea cultivation in Mirzapur district. With the ability to identify complexities of non-linear trends with high values of R-square and low values of error measure, the model is the best one to be used to analyze and forecast the variation of area under pea cultivation. Greater. model accuracy using moving averages further. attest to the significance of smoothing data in agricultural trend analysis.

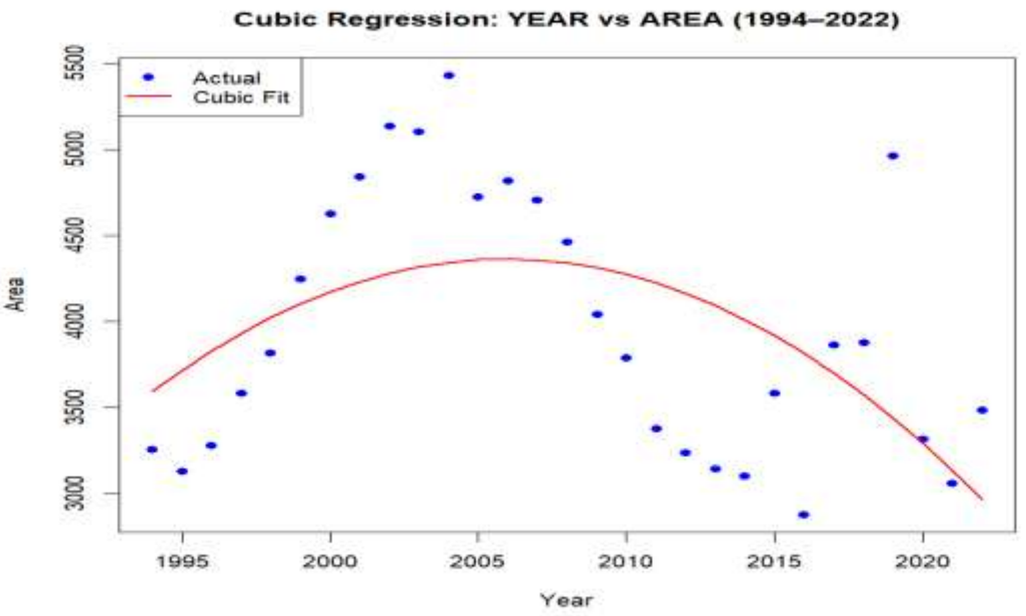

Fig 4.2.37 Fitted Trends of Area of Pea in Mirzapur district of UP

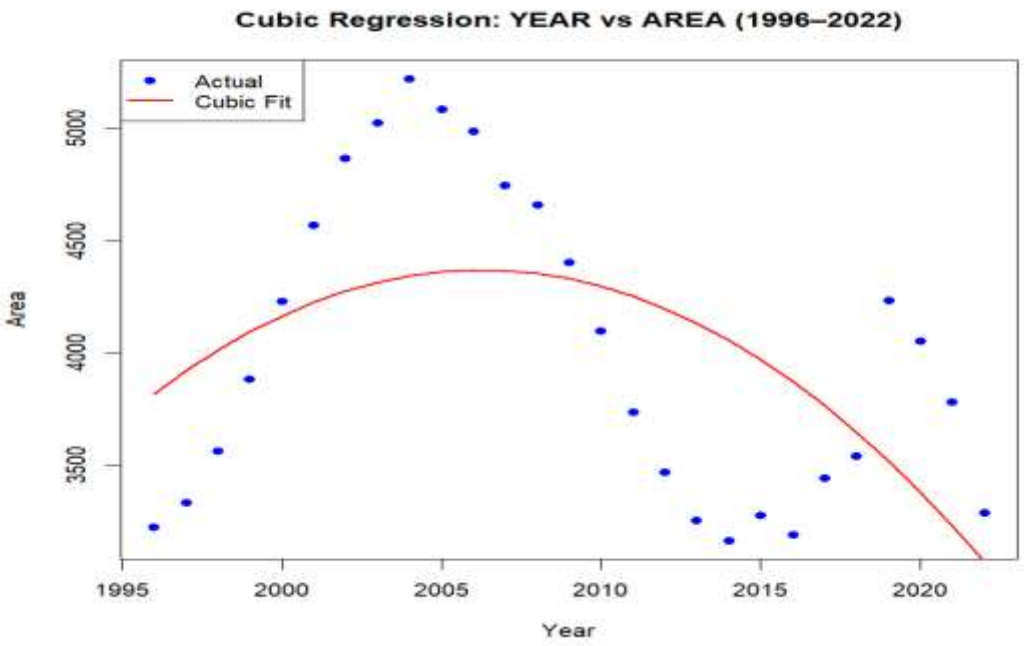

Fig 4.2.38 Fitted Trends of Area for 3-year moving average of Pea in Mirzapur district of UP

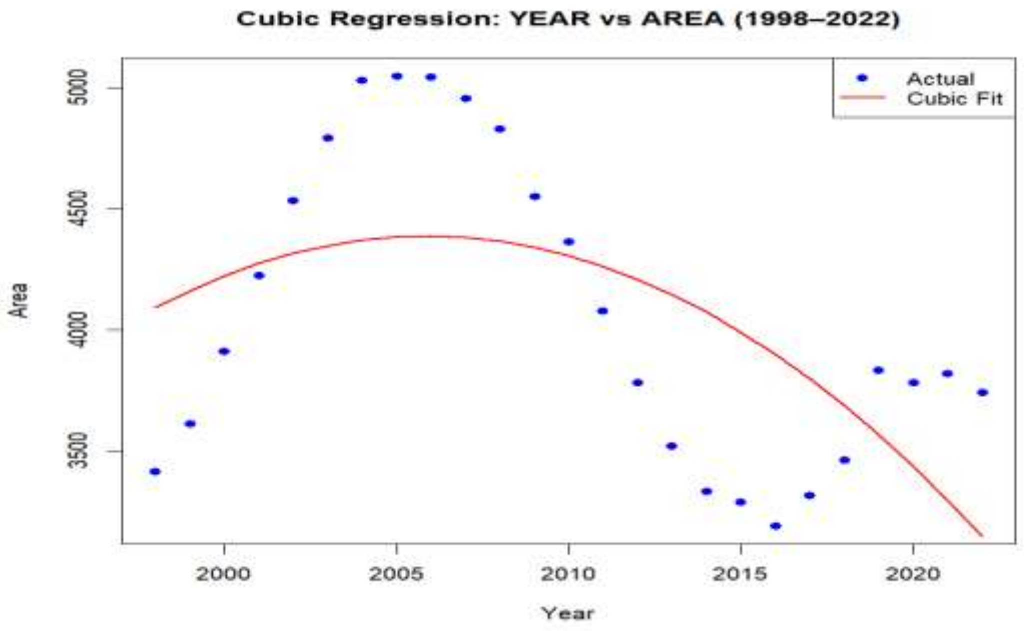

Fig 4.2.39 Fitted Trends of Area for 5-year moving average of Pea in Mirzapur district of UP

Table 4.2.14 Model Evaluation for the production of Pea in Mirzapur district of U.P.

		Parameter				Criteria
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	804465.8	-377.11			0.07
	3MA	911919*	-430.15*			0.13
	5MA	1109770**	-527.99**			0.21
Logarithmic	Actual	578714	-75477			0.07
	3MA	6601540**	-861731**			013
	5MA	810469**	-1059205**			0.21
Quadratic	Actual	-3.6**	35422.7**	-88.37**		0.29
	3MA	-4.04**	403658.23**	-100.56**		0.48
	5MA	-3.9**	395873.6**	-98.60**		0.53
Cubic	Actual	**-7.2***	**1.08***	**-53703.8***	**8.90***	**0.41**
	3MA	**-1.0****	**150576782****	**-7.4851.4****	**12.40****	**0.73**
	5MA	**-1.3****	**1.95****	**-97280.3****	**16.11****	**0.86**
Power	Actual	151.85	-18.55			0.09
	3MA	155.62*	-19.04*			0.14
	5MA	181.64**	-22.46**			0.23
Exponential	Actual	29.34**	-0.009			0.09
	3MA	29.85**	-0.009			0.14
	5MA	33.28**	-0.01*			0.23

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

Table 4.2.14 demonstrates that for actual data, the cubic model was the best among all the models under comparison. The model produced a fair R-square value of 0.41, which was significantly higher than Linear, Logarithmic, and Quadratic models.

With 3-Year Moving Average (3MA) data, the cubic model behaved much better as it was able to capture the short-run smoothing effect of the fluctuations. The value of R-squared for the model was 0.73, showing extremely high model fitness.

The best results were obtained using 5-Year Moving Average (5MA) data. The cubic model again ranked on top of all the other models with a very impressive value of R-square of 0.86. This implies that the 5MA data, since it was smooth, allowed the cubic model to express the trend of output in the long run to the highest degree of precision.

These results eminently demonstrate that the cubic model was superior to other models for all data sets, actual, 3MA and 5MA. Using specifically 5MA data, the model was extremely statistically powerful and precise, and therefore the best to employ in analyzing and forecasting the production of peas in the Mirzapur district. Model statistics improvement by data smoothing indicates the value of moving averages to smooth time series data in agricultural forecasting.

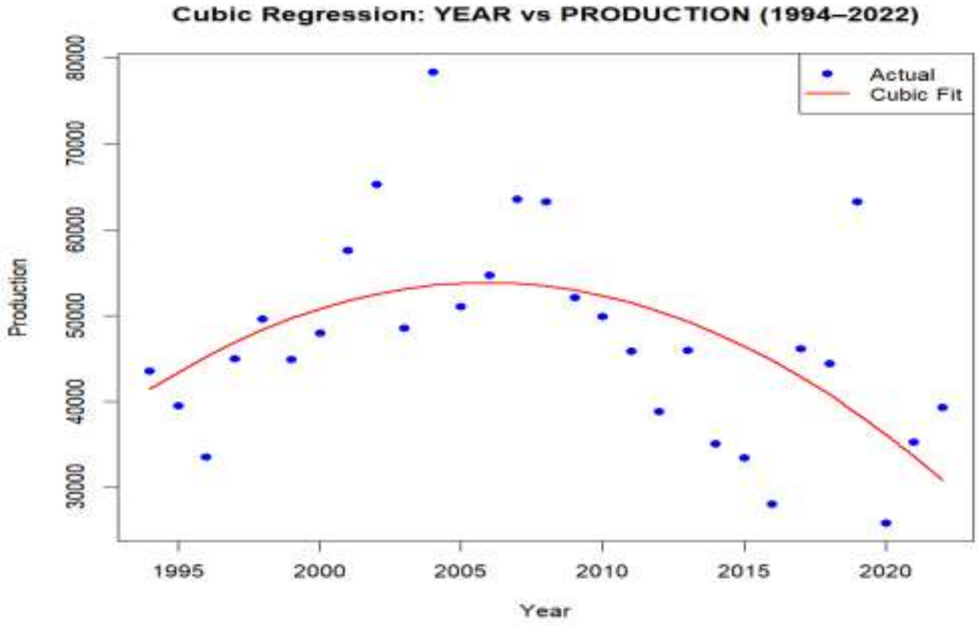

Fig 4.2.40 Fitted Trends of Production of Pea in Mirzapur district of UP

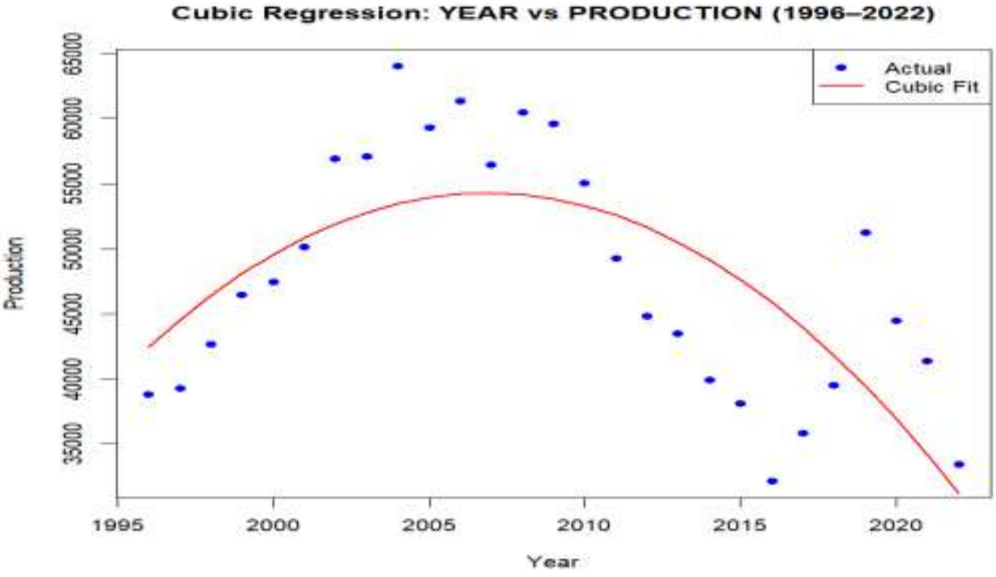

Fig 4.2.41 Fitted Trends of Production for 3-year moving average of Pea in Mirzapur district of UP

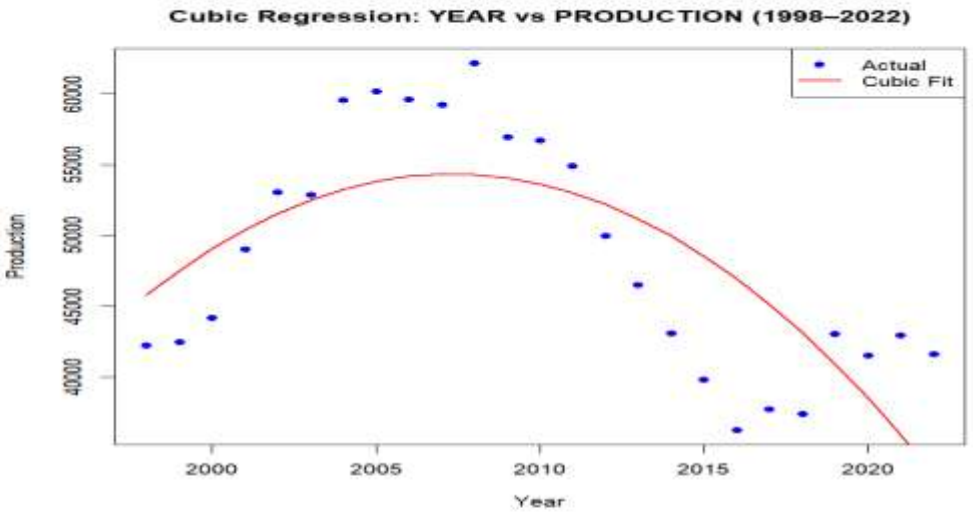

Fig 4.2.42 Fitted Trends of Production for 5-year moving average of Pea in Mirzapur district of UP

Table 4.2.15 Model Evaluation for the yield of Pea in Mirzapur district of U.P.

		Parameter				**Criteria**
Model		**a**	**b**	**c**	**d**	R square
Linear	Actual	89.76	-0.03			0.04
	3MA	77.17	-0.03			0.06
	5MA	62.04	-0.24			0.04
Logarithmic	Actual	602.89	-77.71			0.04
	3MA	506.81	-65.08			0.06
	5MA	391.494	-49.90			0.04
Quadratic	Actual	-25481.6	25.43	-0.006		0.10
	3MA	-25481.6	25.43	-0.06		0.10
	5MA	-41992.1**	41.84**	-0.01**		0.39
Cubic	Actual	**4967078**	**-7433.73**	**3.70**	**-0.0006**	**0.11**
	3MA	**5922467.25**	**-8864.92**	**4.42**	**-0.0007**	**0.46**
	5MA	**6462112**	**-9667.47**	**4.82**	**-0.0008**	**0.59**
Power	Actual	58.41	-7.35			0.04
	3MA	48.56	-6.06			0.07
	5MA	36.69	-4.49			0.05
Exponential	Actual	9.83	-0.003			0.04
	3MA	8.55*	-0.003			0.08
	5MA	6.99	-0.002			0.05

1. * Imply significance at a 5% level of significance
2. ** Imply significance at a 1% level of significance

From Table 4.2.15 for the actual dataset, the cubic model was the strongest predictor among all models. Its R-square was 0.11 greater than those of Linear (0.04), Logarithmic (0.04), and Quadratic (0.10) models. Although actual data analysis did not yield a good model fit in general, the cubic model still yielded relatively good performance.

There was a significant increase in the model precision with 3-Year Moving Average (3MA) data. The cubic model once more proved to be better than others, with a significant increase in R-square to 0.46.

5-Year Moving Average (5MA) data provided the best performance of the model in general. The Cubic model produced the highest R-square of 0.59, which demonstrated high model fit, irrevocably proving the superiority of the Cubic model to predict long-term yield.

Overall, across all three data sets (Actual, 3MA, and 5MA), the best and most appropriate model of pea yield dynamics in Mirzapur district was the Cubic regression model. The model performed significantly better using smoothed data, and the highest rate of prediction was obtained with 5MA data. The research shows that cubic models, when appropriately combined with adequate smoothing procedures, have the potential to be valid tools in agricultural yield forecasting and policy-level decision-making.

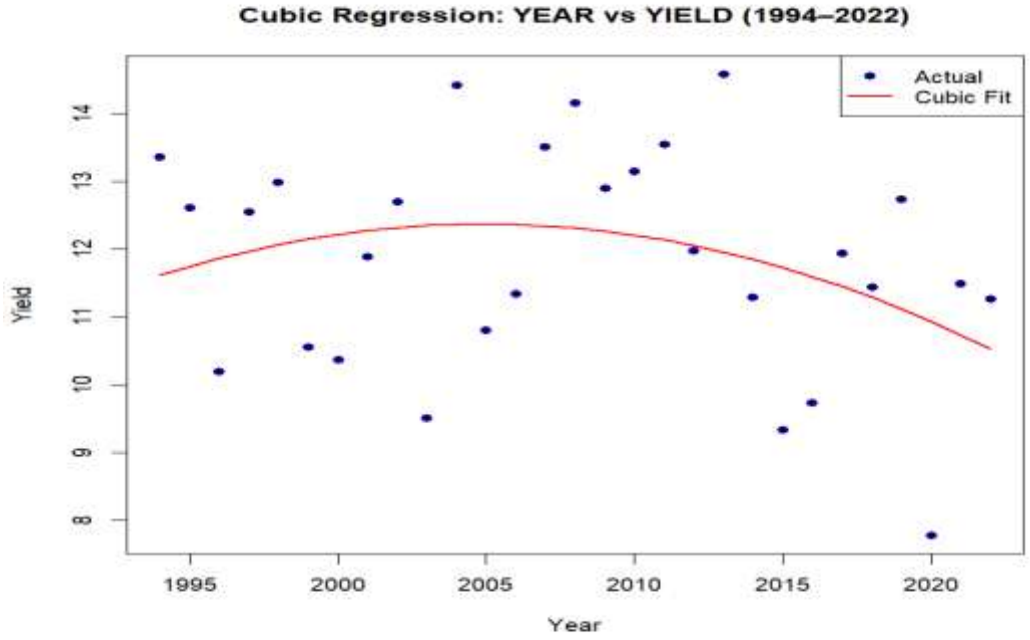

Fig 4.2.43 Fitted Trends of Yield of Pea in Mirzapur district of UP

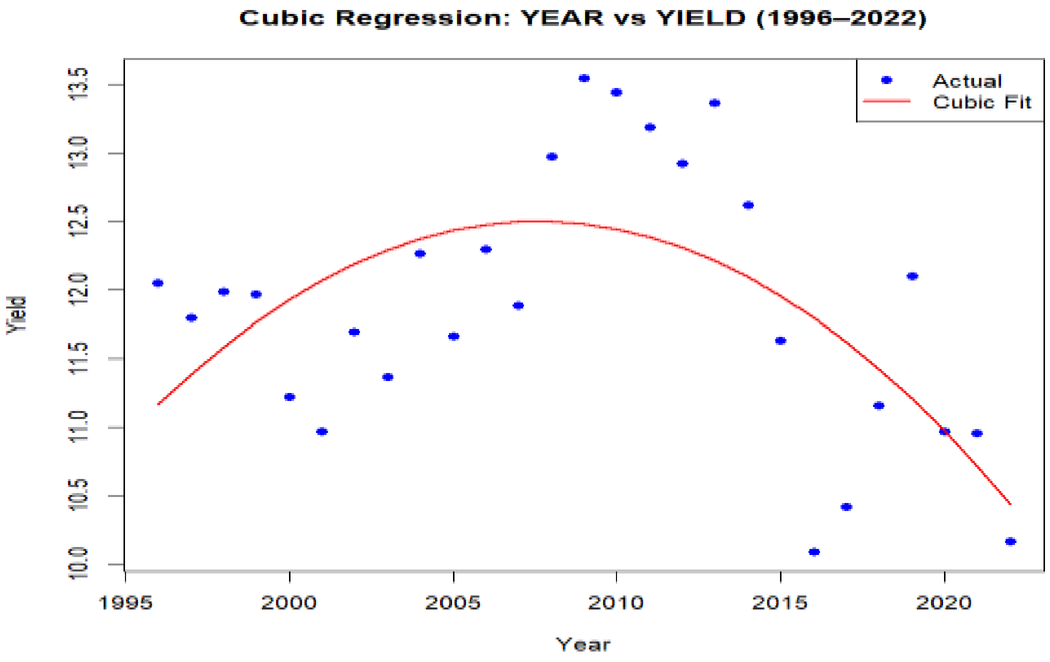

Fig 4.2.44 Fitted Trends of Yield for 3-year moving average of Pea in Mirzapur district of UP

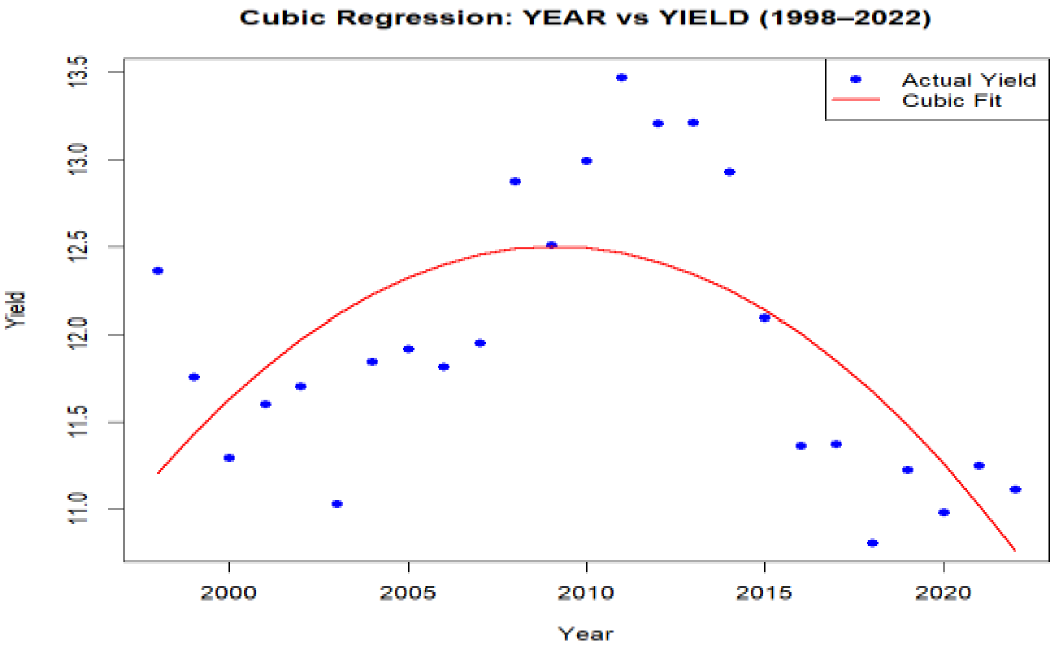

Fig 4.2.45 Fitted Trends of Yield for 5-year moving average of Pea in Mirzapur district of UP

4.3 Validation of models based on various statistical coefficients and measures, including decomposition analysis

4.3.1 Statistical Coefficients and Measures

The values of various statistical measures, i.e., the coefficient of variation (CV) and coefficient of determination (R^2) and the area, production and yield of pulses in Mirzapur district are depicted in Tables 4.3.1, 4.3.2, and 4.3.3, respectively, and the values of R^2 are obtained on fitting linear models to the respective time series data on area, production and yield of pulses in Mirzapur district of U.P.

Table 4.3.1 Values for the statistical coefficients of the area of Pulses based on the linear model

Pulses	C.V.			R Square		
	3-year MA	5-year MA	Overall-year	3-year MA	5-year MA	Overall-year
Arhar	6.15	4.93	9.42	0.66	0.81	0.22
Gram	15.27	14.03	15.92	0.84	0.88	0.79
Pea	17.07	15.49	19.17	0.11	0.21	0.06
Lentil	12.67	11.11	15.07	0.006	0.042	0.001
Urad	13.64	13.17	16.10	0.47	0.71	0.34

Coefficient (statistical statistics) analysis of area under cultivation of major pulse crops like Arhar, Gram, Pea, Lentil and Urad as shown in Table 4.3.1, gives remarkable findings on data variability along with long run trend through Coefficient of Variation (C.V.). The C.V. values, measuring the degree to which the region has varied, indicate that Pea has varied most with 17.07% in the three-year moving average, 15.49% in the five-year moving average and 19.17% in the entire period. This would mean that the region under Pea production has largely been uneven and unreliable. Gram also indicates a high degree of variation with C.V. coefficients of variation of 15.27% (three-year), 14.03% (five-year), and 15.92% (total) and the highest year-to-year variations. Urad also proved to react in the same way with C.V. percentages of 13.64%, 13.17%, and 16.10% for three-year, five-year, and total years, respectively. Lentil, comparatively more consistent, but also shows high variation with 12.67% (three-year), 11.11% (five-year), and 15.07% (total). Arhar, on the other hand, experiences minimum fluctuation among the five pulses with C.V. 6.15%, 4.93%, and 9.42% returns, illustrating a fairly stable year after year field of cultivation.

The R-square measures the linear fit they support, measuring the degree to which the variation of the area is explained by the trend. Gram has the highest R-square measures with the highest linear fit of 0.84 for the three-year moving average, 0.88 for the five-year average and 0.79 for the overall-year data. This indicates a year-wise decrease in the Gram area is linear and statistically relevant. Arhar is quite highly correlated with R-square of 0.66 (three-year), 0.81 (five-year) and 0.22 (all together), which indicates some predictability, particularly medium to short term.

Urad is lagging with R-square of 0.47, 0.71, and 0.34, which indicate a moderate degree of explanation by the trend model. But Pea and Lentil have very weak trend relationships. R-square values for Pea are 0.11 (three-year), 0.21 (five-year), and 0.06 (all), whereas the same for Lentil are very poor at 0.006, 0.042, and 0.001, respectively. The low values suggest that the area patterns of Pea and Lentil are highly irregular and not well expressed by linear models.

Overall, the outcome is that Gram has the strongest and most statistically significant decreasing trend of area under cultivation, whereas Pea and Lentil are extremely volatile with a bad model fit, reflecting randomness or non-linearity in direction over time. Arhar and Urad lie in between the two with moderate volatility and decent model strength, especially in the five-year moving average interval. The research focuses on the intervention to minimize variation and maximize uniformity in Pulses production, especially Pea and Lentil, and maintaining gains in Gram and Urad through improved crop planning, policy support, and resource mobilization.

Table 4.3.2 Values for the statistical coefficients of the production of Pulses based on the linear model

Pulses	C.V.			R Square		
	3-year MA	5-year MA	Overall-year	3-year MA	5-year MA	Overall-year
Arhar	18.48	15.24	27.60	0.14	0.11	0.07
Gram	14.44	10.89	21.97	0.27	0.31	0.17
Pea	19.61	17.12	25.39	0.14	0.21	0.07
Lentil	17.78	13.98	25.43	0.09	0.07	0.07
Urad	19.43	14.06	29.79	0.13	0.08	0.04

The analysis of statistical coefficients for the production of large pulse crops, i.e., Arhar, Gram, Pea, Lentil, and Urad, as in Table 4.3.2, is useful to determine variability and predictability of trends in pulse production over years using the values of Coefficient of Variation (C.V.) and R Square. The C.V. values, i.e., relative volatility of production, show Urad to be most volatile at 19.43% for the three-year moving average, 14.06% for the five-year moving average and 29.79% for the whole period, reflecting extreme inconsistency in production. Likewise, Arhar is highly volatile with C.V. values of 18.48% (three-year), 15.24% (five-year), and 27.60% (whole period). Pea and Lentil also show significant variations, with Pea showing 19.61%, 17.12%, and 25.39% and Lentil showing 17.78%, 13.98%, and 25.43% for the respective years. Gram, however, varies, showing relatively lower C.V. percentages of 14.44% (three-year), 10.89% (five-year), and 21.97% (total) and depicting relatively more consistent production patterns among the five crops.

R-square values, which represent the extent to which there is a linear trend in production over time, are highest in Gram, exhibiting moderate model fit as well as more stable trends. R-square for Gram is 0.27 (three-year), 0.31 (five-year), and 0.17 (total), which suggests that time can explain the production variations satisfactorily. The other pulse crops exhibit very poor linear relationships. Arhar has R-square of 0.14 (three-year), 0.11 (five-year), and 0.07 (overall) and indicates very poor trend predictability. Pea is superior in the five-year average (0.21) but low at 0.14 and 0.07 for the three-year average and overall, respectively. Lentil has R-square values of 0.09, 0.07, and 0.07, and Urad has the poorest fit of 0.13 (three-year), 0.08 (five-year), and only 0.04 in the overall trend, thus validating that yield variability in these crops is poorly accounted for by basic linear time models.

In conclusion, it is brought to light that all pulse crops have high variability in production, wherein Urad and Arhar patterns are especially erratic. Gram is comparatively more stable and consistent with higher values of R-square. The low, if not overall low, R - square values in all crops indicate that weather volatility, pest epidemics, availability of inputs, and market forces will be highly significant determinants of pulse production instead of mere time. Such results support the reality of crop-specific interventions, enhanced forecasting systems, and rational risk-growth prevention measures in order to stabilize pulse production and make it predictable over time.

Table 4.3.3 Values for the statistical coefficients of the yield of Pulses based on the linear model

Pulses	C.V.			R Square		
	3-year MA	5-year MA	Overall-year	3-year MA	5-year MA	Overall-year
Arhar	14.93	12.66	22.01	0.01	0.002	0.02
Gram	10.22	8.74	16.69	0.41	0.65	0.11
Pea	8.42	6.96	13.88	0.06	0.04	0.04
Lentil	9.49	7.53	15.70	0.44	0.61	0.19
Urad	21.94	18.86	27.28	0.51	0.62	0.30

Coefficient of variation (C.V.) and model fit (R-square) analysis of the yield of major pulse crops namely Arhar, Gram, Pea, Lentil and Urad, as presented in Table 4.3.3, provides a close examination of variability (C.V.) and model fit (R-square) for three-year, five-year moving average, and overall tenure. The C.V. measures provide an idea of the stability or volatility of the yield of earlier years. Among the pulses, Urad exhibits the highest yield variation of 21.94% for the three-year moving average, 18.86% for the five-year moving average and 27.28% for the whole period, indicating high year-to-year Yield variabilities. Arhar is very variable with C.V. percentages of 14.93%, 12.66%, and 22.01% for the respective periods, indicating yield volatility.

On the other hand, Pea is most stable at 8.42% (three-year), 6.96% (five-year), and 13.88% (all above), which suggests relatively uniform output. Gram and Lentil are at mid-level, with Gram showing 10.22%, 8.74%, and 16.69%, while Lentil shows 9.49%, 7.53%, and 15.70% respectively, for the same period of time.

The R-square values of the strength of the relationship between yield and time are highly varying between crops. The best fit model is that of Urad with R-square values of 0.51 (three-year), 0.62 (five-year), and 0.30 (general), indicating a strong to moderate linear pattern in the growth of the yield. Lentil also shows comparatively high values of 0.44 (three-year), 0.61 (five-year), and 0.19 (total), which show a good-fitting rising trend in yield. Gram shows moderate explainability with R-square measures of 0.41, 0.65, and 0.11, respectively, and shows some consistency but lesser long-term explanation.

On the other hand, Pea and Arhar hold very low trend explainability. R-square statistics for Arhar are 0.01, 0.002, and 0.02, while those for Pea are 0.06, 0.04, and 0.04, which implies that their yield variability cannot be explained using time-based models. This would suggest that their yield would be controlled by external or non-linear sources instead of a trend.

In total, the analysis illustrates evidence of Urad and Lentil having the most reliable and consistent yield improvement trends, backed by moderate to high R-square values and variable-controlled variability. Gram also indicates a positive but less dependable trend. Arhar and Pea, on the other hand, illustrate low predictability and high variability, particularly with Arhar. Such outcomes enhance focus on improvement of agronomic methods and support systems for low-yielding stable varieties of crops, along with further strengthening and widening gains in the case of crops like Urad, Lentil, and Gram through enhanced technology extension, stress-tolerance varieties, and precision agriculture operations.

4.3.2 Instability Index

The Values of Cuddy-Della Valle instability index (I) for area, production and yield of pulses in Mirzapur are depicted in Table 4.3.4.

Table 4.3.4 Instability Index of area, production and yield of Pulses

	AREA			PRODUCTION			YIELD		
Pulses	3-year MA	5-year MA	Overall-year	3-year MA	5-year MA	Overall-year	3-year MA	5-year MA	Overall-year
Arhar	3.58	2.14	8.32	17.08	14.35	26.44	14.81	12.65	21.80
Gram	5.32	4.16	7.22	11.31	8.54	19.68	7.48	4.80	15.91
Pea	16.09	13.75	18.01	18.25	15.14	24.02	8.13	6.79	14.03
Lentil	12.36	10.59	14.42	16.32	13.07	23.10	6.72	4.52	13.88
Urad	9.28	7.01	12.31	17.16	13.45	25.28	14.31	11.48	21.39

The Instability Index study for the area, production and yield of the key pulse crops Arhar, Gram, Pea, Lentil and Urad is as given in Table 4.3.4. This gives a general idea about the instability of these parameters for the three-year moving average, five-year moving average and the entire study period.

For the region, the instability index shows Pea was most significantly fluctuating with 16.09% (three-year), 13.75% (five-year), and 18.01% (overall) values showing high volatility in its region of cultivation throughout the years. Lentil and Urad also possess high instability in regions with overall-year values of 14.42% and 12.31%, respectively. Gram shows less area instability of 5.32%, 4.16%, and 7.22%, whereas Arhar shows minimum area instability at 3.58%, 2.14%, and 8.32% for the respective periods, which suggests relative stability.

Production-wise, maximum instability is experienced in Arhar with a total instability index of 26.44%, followed by Urad (25.28%), Lentil (23.10%), and Pea (24.02%). These are broad ranges of year-to-year fluctuation in pulse production due to maybe weather, epidemic, or technology and management practice fluctuations. Gram is the one having the lowest production instability with 11.31% (three-year), 8.54% (five-year), and 19.68% (total), indicating relatively stable production levels in the case of other pulses.

While in yield, Urad again scores the highest instability with 14.31% (three-year), 11.48% (five-year), and 21.39% (all), and scores the highest level of change in yield. Highest yield instability is also scored by Arhar with an overall index of 21.80%, followed by Gram

(15.91%), Lentil (13.88%), and Pea (14.03%). While all the crops show high variations in yield, Lentil and Pea show relatively lesser instability for the period of five years, with 4.52% and 6.79%, respectively. The instability in production and yield observed for Pea and Gram suggests vulnerability to climatic or market shocks. These findings are comparable to those of Chatterjee *et al*. (2014), who found rabi pulses to have higher instability than kharif pulses across India. Kumari and Malik (2023) also reported medium to high instability in the yield and production of pulses in states like Uttar Pradesh and Rajasthan. Similarly, Bisht and Kumar (2018) noted that despite productivity growth, area instability remained a concern in several regions.

Overall, the instability index indicates that Pea is most unstable by area, Arhar and Urad are most unstable by production and yield, while Gram is relatively more stable by all three indicators. These findings emphasize the need for crop-wise interventions: sustaining stabilized areas under cultivation of Pea and Lentil, inducing improvement in consistency in production of Arhar and Urad, and sustaining Gram's relatively stable trend. Overall, policies that will enhance yield, control risk (e.g., insurance) and contribute to stable input supply are going to eliminate these instabilities and support the pulse industry.

4.3.3 Decomposition Analysis

Decomposition analysis was carried out to find the contribution of area effect, yield effect and interaction effect for the overall period (1994-22) of pulses and also to find the contribution of the Mean area effect, mean yield effect and their interaction effect for the overall period of pulse crop.

Table 4.3.5 Decomposition analysis of Pulses by area effect and the yield effect and the interaction effect.

Pulses	Area Effect (%)	Interaction (%)	Yield effect (%)
Arhar	120.22	3.52	-23.75
Gram	24.30	-7.15	82.84
Pea	161.14	11.38	-72.52
Lentil	75.57	3.63	20.80
Urad	1158.00	-253.31	-804.69

The decomposition analysis of pulse production due to area effect, yield effect, and their interaction, in the way illustrated in Table 4.3.5, provides a clear insight into each factor's contribution to the overall change in production in the case of major pulse crops viz., Arhar, Gram, Pea, Lentil and Urad.

For Arhar, the area effect is strongly positive at 120.22%, which suggests that the growth in area has played a major role in promoting production growth. But this gain is partly neutralized by a negative yield effect of -23.75%, which suggests that falling yield has removed some of the area-based production gains. The interaction effect is 3.52%, contributing marginally to the total change.

The main effect for Gram is the yield effect with a single-digit high positive value of 82.84%, suggesting a high Yield gain. The area effect is low at 24.30%, and the interaction effect is negative at (-7.15%), minutely decreasing the overall gain.

For Pea, the area effect is very high at 161.14%, suggesting area growth as the major cause of production. Nevertheless, the yield effect is generally negative at -72.52%, weakening the benefits of area growth. The interaction effect is positive (11.38%), but only marginally contributes to the overall impact.

Lentil provides a balanced situation with a favorable area effect of 75.57% and a favorable yield effect of 20.80%, indicating that increased area and improved Yield both contributed to increased production. The interaction effect is slight but favorable (3.63%), lending further support to the gain as a whole.

Urad shows an extreme and unfavorable trend. While the area effect is extremely high at 1158.00%, the yield effect is amazingly negative at -804.69%, and so is that of interaction (-253.31%). This shows that despite the fact that the cultivated area expanded hugely, the yield declined so steeply that it overcompensated for the area effect to provide a net negative contribution to production. Both the negative interaction and yield effects offset the potential for expansion in area.

In general, this decomposition analysis reveals that for Gram and Lentils, yield improvement is the single most significant cause of production increases. This reflects the national-level findings by Devi *et al.* (2017), Kumar *et al.* (2018) and Balai *et al.* (2024), who similarly reported that the yield effect had become the predominant contributor to pulse production growth across India. For Pea and Arhar, area expansion has also been the principal driver, but it is under threat from falling yields. In contrast, the case of Urad is alarming as significant area increases have been completely eclipsed by steep Yield declines, requiring surgery in yield-enhancing technology and agronomic management. These observations are imperative to develop pulse-specific measures that align area enlargement with yield increments in order to appreciably enhance production sustainably.

Table 4.3.6 Decomposition analysis of Pulses by mean area effect, mean yield effect and interaction effect

Pulses	Mean Area Effect (%)	Interaction (%)	Mean Yield effect (%)
Arhar	72.91	-2.22	29.31
Gram	149.63	14.20	-63.84
Pea	90.89	-1.84	10.95
Lentil	-567.89	-59.75	727.64
Urad	-187.19	-65.44	352.64

The decomposition analysis of pulses, because of the mean area effect, mean yield effect, and the interaction effect, is shown in Table 4.3.6. According to the results, significant variation occurs between different pulse crops in terms of the contribution of the aforementioned components to the change in production.

For Arhar, the average area effect (72.91%) was the most influential causal determinant of an increase in production, coupled with a positive average yield effect (29.31%). However, the interaction effect (-2.22%) was marginally negative, indicating a very negligible combined effect of area and yield. It implies that area expansion, coupled with marginal increases in yield, was primarily responsible for differences in Arhar production.

For Gram, growth of production was mostly area-driven (149.63%), though the positive interaction effect was also at play (14.20%). The mean yield effect (-63.84%) was, however, significantly negative and reflects that yield performance declined sharply even as area rose. The implication is that yield loss was offset by area expansion, pointing to a productivity constraint in Gram cultivation.

Both mean area effect (90.89%) and mean yield effect (10.95%) were positive for Pea, but the interaction effect was negative to a value of -1.84%. It indicates that rises in production in Pea were the result of combined rises in area under cultivation and a rise in yield, with minimum interaction between the two.

Lentil is a reverse case. Mean yield effect (727.64%) was a preponderant driving force behind the growth in production, while mean area effect (-567.89%) and interaction effect (-59.75%) were negative. This significantly indicates that growth in production in Lentil relied completely on yield, compensating for steep falls in area under cultivation. Technological change, improved management practices, or increased adoption of high-yielding varieties perhaps propelled productivity in Lentil, so.

For Urad, the average yield effect (352.64%) played the major role in increasing production, while the area effect (-187.19%) and the interaction effect (-65.44%) were negative. Trend direction shows that, similar to the situation with Lentil, Urad's growth in production was driven by yields, while shrinking area under cultivation checked overall growth.

Overall, decomposition analysis picks up differential dynamics in pulse crops. Arhar and Pea picked up on account of simultaneous area and yield rises, Gram was largely area-led with constraint on yield, and Lentil and Urad registered high yield-led growth in spite of adverse area trends. The results represent the imperative of productivity boost through technological intervention, greater efficiency in the utilization of inputs, and application of superior quality varieties, particularly in cases like Gram, where stagnation of yields still prevails. These are concurring results to those of Kumar *et al.* (2018), which saw yield as the overarching contributor to pulse production over decades. Devi *et al.* (2017) also noted that the effect of yield, and not area, was responsible for increasing production during the post-1994 era. More *et al.* (2015) noticed that yield and area contributed erratically over decades and crops, but the interaction effect continued to be low, just like the trend in this study.

4.3.4 Percentage Change

The percentage change analysis in Table 4.3.7 for the area, production and yield of major pulse crops Arhar, Gram, Pea, Lentil and Urad across three-year moving average, five-year moving average, and overall periods provides a clear picture of the directional trends in pulse cultivation performance in Mirzapur district of U.P.

Table 4.3.7 Percentage Change in area, production and yield of Pulses

Pulses	AREA			PRODUCTION			YIELD		
	3-year MA	5-year MA	Over-all year	3-year MA	5-year MA	Over-all year	3-year MA	5-year MA	Over-all year
Arhar	-10.98	-13.18	2.93	-26.61	-14.38	-12.34	-18.38	-0.72	-14.83
Gram	-31.43	-31.32	-29.40	-30.38	-17.11	-35.49	1.20	20.78	-8.63
Pea	2.04	9.60	7.06	-13.92	-1.50	-9.74	-15.59	-11.35	-15.70
Lentil	7.26	13.79	4.80	26.25	51.84	23.06	17.77	33.07	17.43
Urad	-0.71	-15.24	-21.88	48.42	19.67	2.72	44.21	38.20	31.48

For the area, the data shows that Gram experienced the sharpest decline, with percentage changes of -31.43% (three-year), -31.32% (five-year), and -29.40% (overall), reflecting a consistent contraction in its cultivated area. Urad also faced a notable decline with -0.71% (three-year), -15.24% (five-year), and -21.88% (overall), indicating a worsening area trend over time. Arhar displayed mixed behavior, with short-term declines of -10.98% and -13.18% in the three- and five-year averages, respectively, but a slight increase of 2.93% in the overall period, suggesting partial long-term recovery. In contrast, Lentil and Pea showed positive area growth, with Lentil increasing by 7.26% (three-year), 13.79% (five-year), and 4.80% (overall), and Pea by 2.04%, 9.60%, and 7.06%, respectively.

In terms of production, Gram again shows a sharp decline, with -30.38% (three-year), -17.11% (five-year), and -35.49% (overall), followed by Arhar with declines of -26.61%, -14.38%, and -12.34%, respectively. Pea also recorded significant production decreases of -13.92% (three-year), -1.50% (five-year), and -9.74% (overall). In contrast, Lentil and Urad showed strong positive growth in production. Lentil had percentage increases of 26.25%, 51.84%, and 23.06%, while Urad showed an even more dramatic rise with 48.42% (three-year), 19.67% (five-year), and 2.72% (overall), highlighting a significant boost in Yield over time.

For yield, Urad demonstrated exceptional gains, with increases of 44.21% (three-year), 38.20% (five-year), and 31.48% (overall), followed by Lentil, which rose by 17.77%, 33.07%, and 17.43%, respectively. Gram also showed yield improvement in the short term

(1.20% in three-year and 20.78% in five-year), though its overall change was negative (-8.63%), suggesting possible inconsistency. In contrast, Pea and Arhar experienced declines in yield, with Pea showing -15.59%, -11.35%, and -15.70%, and Arhar showing -18.38%, -0.72%, and -14.83% for the respective time frames, indicating declining Yield.

In conclusion, the analysis reveals that Lentil and Urad performed strongly across all three dimensions, area, production, and yield, especially in terms of yield improvement. Gram showed the steepest decline in both area and production despite slight yield gains in recent years, while Pea and Arhar consistently declined in Yield, with Arhar showing slight area recovery but persistent declines elsewhere. These trends emphasize the importance of targeted interventions to reverse declining patterns in Gram, Pea, and Arhar, while also enhancing support for Lentil and Urad, which have demonstrated promising growth and potential for further development.

4.3.5 Validation of Model Performance

Validation is a crucial stage in building models, which ensures that the forecast models reflect the data realistically and can generalize to unseen data. Under this study section, a comprehensive validation of using linear and non-linear regression models on three agriculture indicators, Area, Production, and Yield. The models are experimented with three statistical measures: R-square (coefficient of determination), RMSE (Root Mean Square Error) and MAPE (Mean Absolute Percentage Error). The models are analyzed under true conditions as well as by using 3-year (3MA) and 5-year moving averages (5MA).

Table 4.3.8 Validation of model performance for predicting area, production and yield of Gram

		Area			**Production**			**Yield**		
Model		R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**
Linear	Actual	0.794	1108.415	0.066	0.1731	31864.66	0.1629	0.111	1.639	0.123
	3MA	0.8464	895.768	0.0542	0.274	18718	0.0984	0.4171	0.7841	0.0586
	5MA	0.8879	696.852	0.0376	0.3159	3522.74	0.071	0.6598	0.508	0.0394
Logarithmic	Actual	0.795	1105.309	0.066	0.173	31864.66	0.1609	0.111	1.639	0.123
	3MA	0.8474	892.672	0.0541	0.2761	18704.75	0.0983	0.416	0.784	0.058
	5MA	0.888	693.985	0.0375	0.3171	13511.33	0.071	0.6588	0.5096	0.0395
Quadratic	Actual	0.9153	711.516	0.033	0.506	24609.02	0.1221	0.296	1.458	0.112
	3MA	0.9577	469.68	0.0223	0.6336	13305.13	0.0635	0.5713	0.6724	0.0493
	5MA	0.9814	283.677	0.0151	0.7273	8537.786	0.044	0.8085	0.3818	0.0338
Cubic	Actual	**0.924**	**673.209**	**0.031**	**0.518**	**24308.25**	**0.1228**	**0.322**	**2.063**	**0.109**
	3MA	**0.9621**	**445.122**	**0.0192**	**0.6345**	**13289.6**	**0.06334**	**0.5803**	**0.66527**	**0.04851**
	5MA	**0.9866**	**240.371**	**0.0109**	**0.7579**	**8043.38**	**0.041**	**0.8237**	**0.3663**	**0.0313**
Power	Actual	0.8072	0.0671	0.006	0.165	0.1888	0.0129	0.106	0.153	0.052
	3MA	0.8641	0.0531	0.0051	0.271	0.1131	0.0079	0.4225	0.074	0.025
	5MA	0.903	0.041	0.0034	0.312	0.0854	0.00586	0.665	0.048	0.016
Exponential	Actual	0.8062	0.067	0.006	0.164	0.188	0.012	0.107	0.153	0.052
	3MA	0.8062	0.0672	0.00631	0.2671	0.1131	0.0079	0.4233	0.074	0.025
	5MA	0.86316	0.05325	0.0051	0.3111	0.0854	0.0058	0.666	0.0481	0.016

On the basis of Table 4.3.8 for Gram Area prediction, the Cubic model possessed the highest accuracy. In the original data, the Cubic model possessed R-square (0.924), RMSE (673.209), and MAPE (0.031). Performance improved further after using moving averages. With a moving average of 3 years, the Cubic model possessed R-square (0.9621), RMSE (445.122), and MAPE (0.0192). The best performance was realized using the 5-year moving average, as the Cubic model provided an R-square of 0.9866, an RMSE of 240.371, and an MAPE of 0.017, which is highly fit with minimal prediction error.

In Production, the Cubic model performed best among all the models. The actual data were R-square 0.518, RMSE (24308.25), and MAPE (0.1228). Cubic model's performance improved by incorporating the 3-year moving average to an R-square (0.6345), an RMSE (13,289.60), and an MAPE (0.06334). The 5-year moving average gave the highest fit with an R-square of 0.7579, RMSE of 8,043.38, and a MAPE of 0.041, a large decrease in error and a considerable increase in explanatory power.

For Yield prediction, the Cubic model provided the highest accuracy. On actual data, the model produced an R-square of 0.332, RMSE of 2.063, and MAPE of 0.109. The 3-year moving average increased the values to R-square of 0.5803, RMSE of 0.66527, and MAPE of 0.04851. The best results were achieved when the 5-year moving average was used, and the Cubic model produced R-square of 0.8237, RMSE of 0.3663, and MAPE of 0.0313. What this implies is that the Cubic model, particularly when used with moving averages, is extremely accurate in predicting yield.

The findings squarely place the Cubic regression model, especially using 5-year moving averages, as always having the highest validation statistics among the three parameters. Besides improving the fit of the model with higher R-square values, the use of moving averages minimizes prediction errors as observed from smaller RMSE and MAPE values. These results point to the significance of the choice of models and data smoothing methods to obtain uniform and dependable predictions for agricultural indicators.

Table 4.3.9 Validation of model performance for predicting area, production and yield of Arhar

		Area			Production			Yield		
Model		R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**
Linear	Actual	0.220	1120.98	0.0537	0.0624	33653.8	0.2524	0.0104	2.0294	0.2167
	3MA	0.661	468.79	0.027	0.1458	20672.72	0.1461	0.01558	1.3331	0.1289
	5MA	0.8114	279.69	0.0173	0.1128	17166	0.1327	0.00196	1.1277	0.1156
Logarithmic	Actual	0.2213	1120.475	0.053	0.062	33645.46	0.2523	0.0104	2.029	0.216
	3MA	0.6626	468.077	0.0273	0.146	20662.42	0.1461	0.015	1.332	0.128
	5MA	0.8124	278.87	0.0172	0.1136	17157.93	0.1325	0.00207	1.127	0.115
Quadratic	Actual	0.383	996.924	0.048	0.311	288853.65	0.20881	0.199	1.825	0.189
	3MA	0.7983	361.88	0.0196	0.5593	14848.93	0.111601	0.3941	1.045	0.103
	5MA	0.955	135.373	0.0077	0.7146	9734.619	0.0684	0.5721	0.738	0.069
Cubic	Actual	**0.394**	**987.74**	**0.0486**	**0.3121**	**28825.8**	**0.2073**	**0.204**	**1.819**	**0.186**
	3MA	**0.8008**	**359.64**	**0.0186**	**0.5731**	**14615.4**	**0.11022**	**0.4041**	**1.037**	**0.103**
	5MA	**0.9568**	**133.781**	**0.00751**	**0.7149**	**9731.05**	**0.086**	**0.574**	**0.736**	**0.069**
Power	Actual	0.242	0.0816	0.0054	0.0496	0.289	0.019	0.0061	0.254	0.098
	3MA	0.659	0.0349	0.00281	0.1191	0.174	0.012	0.0123	0.154	0.059
	5MA	0.8194	0.0201	0.0017	0.0875	0.148	0.011	0.0015	0.131	0.053
Exponential	Actual	0.242	0.0817	0.00551	0.0492	0.289	0.019	0.0059	0.255	0.098
	3MA	0.658	0.034	0.00281	0.1183	0.174	0.012	0.012	0.154	0.059
	5MA	0.8184	0.021	0.0017	0.0867	0.148	0.011	0.0014	0.131	0.053

Table 4.3.9 shows that for the Arhar area forecast, the Cubic model worked best among the models. Operating on actual data, the Cubic model reported R-square of 0.394, RMSE of 987.74, and MAPE of 0.0486. Its performance was also upgraded with the use of moving averages. With the 3-year moving average, the Cubic model resulted in an R-square of 0.8008, an RMSE of 359.64, and a MAPE of 0.0186. The highest values were obtained when the 5-year moving average was employed, where the Cubic model gave an R-square of 0.9568, an RMSE of 133.781, and a MAPE of 0.00751. These are typical of a very good fit to the model and low error of prediction.

For Production, the Cubic model was optimal as well. Based on the actual values, its performance was an R-square of 0.3121, an RMSE of 28825.8, and a MAPE of 0.2073. Based on the moving average of 3 years, the Cubic model's performance was an R-square of 0.5731, an RMSE of 14615.4, and a MAPE of 0.11022. The 5-year moving average performed best with R-square of 0.7149, RMSE of 9731.05, and MAPE of 0.086. This is a substantial error reduction as well as an explanatory increase.

In Yield prediction, the best performance was achieved by the Cubic model. On being supplied with actual data, it yielded an R-square of 0.204, an RMSE of 1.819, and a MAPE of 0.109. The 3-year moving average brought these up to an R-square of 0.4041, an RMSE of 1.037, and a MAPE of 0.103. The most accurate result was achieved with the 5-year moving average, where the Cubic model yielded an R-square of 0.736, an RMSE of 0.736, and a MAPE of 0.069. It shows how potent the Cubic model, particularly when paired with moving averages, can be if utilized in forecasting yields.

In general, the results unambiguously show that the Cubic regression model, particularly when it is calibrated to 5-year moving averages, produces the most consistently high validation statistics for all three parameters. Moving averages enhance model fit as indicated by higher R-square levels and reduce prediction error as indicated by lower RMSE and MAPE levels. These results enhance the position of model choice and data smoothing methods in providing accurate and reliable predictions for crop parameters.

Table 4.3.10 Validation of model performance for predicting area, production and yield of Lentil

		Area			**Production**			**Yield**		
Model		R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**
Linear	Actual	0.000954	791.25	0.116	0.0681	10153.39	0.1888	0.191	1.085	0.116
	3MA	0.0063	662.298	0.1086	0.0991	6941.482	0.1346	0.447	0.539	0.054
	5MA	0.0429	567.41	0.094	0.074	5523.24	0.115	0.613	0.358	0.0395
Logarithmic	Actual	0.000946	791.262	0.169	0.0681	10153.5	0.1889	0.191	1.085	0.1166
	3MA	0.00636	662.31	0.1086	0.099	6940.33	0.1346	0.447	0.539	0.054
	5MA	0.042	567.463	0.094	0.0743	5523.12	0.1157	0.612	0.359	0.0395
Quadratic	Actual	0.0061	789.20	0.117	0.0686	10150.69	0.18815	0.1971	1.081	0.116
	3MA	0.0215	657.235	0.107	0.1003	6935.517	0.1335	0.448	0.5388	0.054
	5MA	0.101	549.767	0.091	0.0765	5516.482	0.1156	0.651	0.341	0.038
Cubic	Actual	**0.1868**	**9484.702**	**0.1773**	**0.1868**	**9484.702**	**0.1773**	**0.2086**	**1.0739**	**0.1135**
	3MA	**0.453**	**5404.817**	**0.1011**	**0.453**	**5404.817**	**0.101**	**0.5027**	**0.5117**	**0.05213**
	5MA	**0.767**	**2765.182**	**0.0562**	**0.767**	**2765.182**	**0.05**	**0.827**	**0.2393**	**0.0252**
Power	Actual	0.0031	0.1443	0.013	0.0518	0.23107	0.017	0.1663	0.13881	0.0567
	3MA	0.00304	0.1442	0.0133	0.094	0.1632	0.0123	0.458	0.0672	0.0266
	5MA	0.00871	0.1236	0.0124	0.0754	0.1307	0.011	0.6157	0.0452	0.0191
Exponential	Actual	0.0031	0.1442	0.013	0.0518	0.2311	0.0169	0.1664	0.1388	0.056
	3MA	0.0087	0.1236	0.0124	0.0943	0.1632	0.0123	0.4583	0.0682	0.0256
	5MA	0.0458	0.1059	0.0108	0.0753	0.131	0.011	0.6161	0.0451	0.0194

From Table 4.3.10 Cubic model performed best in forecasting Lentil Area compared to all other models. With actual values, the Cubic model gave an R-square of 0.1868, an RMSE of 9484.702, and an MAPE of 0.1173. With a 3-year moving average, the outcome significantly improved to an R-square of 0.453, an RMSE of 5404.817, and an MAPE of 0.1011. The best model results were obtained by utilizing the 5-year moving average because it caused the Cubic model to attain R-square (0.767), RMSE (2765.182), and MAPE (0.0562). This indicates a lot of improvement in model fit and forecasting as the data are averaged out over extended periods.

For Production forecasting, once more, the Cubic model performed better than the other models. With actual values, it provided an R-square of 0.1868, an RMSE of 9484.70, and a MAPE of 0.1773. For application in a 3-year moving average, R-square was 0.45, while RMSE was 5404.817 and MAPE was 0.101. The 5 moving average also enhanced the model's performance, with R-square improving to 0.767, RMSE to 2765.182, and MAPE to 0.05. The implication is that the Cubic model, especially when used with moving averages, is a better fit and has a lower error in prediction for production data.

In Yield prediction, the Cubic model was best again. Using real data, the model produced an R-square of 0.20, an RMSE of 0.1.0739, and a MAPE of 0.1135. Using a 3-year moving average reduced the R-square to 0.5027, reduced the RMSE to 0.5117, and reduced the MAPE to 0.05213. Despite a moving window of 5 years, Cubic performed well, with an R-square of 0.827, RMSE of 0.2393, and MAPE of 0.0252, indicating extremely high reliability and precision in yield prediction.

Overall, the findings validate that the Cubic regression model, particularly when used together with a 5-year moving average, has the greatest validation statistics for each of the three parameters (Area, Production, and Yield). The use of moving averages significantly enhances the performance of the models, as suggested by better R-square values, and reduces prediction errors as suggested by lower RMSE and MAPE values. These remarks present the importance of model selection and data smoothing techniques in finding stable and trustworthy estimators of lentil crop parameters.

Table 4.3.11 Validation of model performance for predicting area, production and yield of Urad

		Area			**Production**			**Yield**		
Model		R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**
Linear	Actual	0.343	102.709	0.093	0.043	1302.37	0.2207	0.304	1.2821	0.1944
	3MA	0.472	77.963	0.0782	0.132	805.046	0.1593	0.0431	1302.37	0.2207
	5MA	0.7166	55.0749	0.057	0.0839	588.367	0.1186	0.6286	0.6354	0.1045
Logarithmic	Actual	0.343	102.6878	0.0931	0.042	1302.552	0.2207	0.3036	1.282	0.194
	3MA	0.472	77.932	0.0781	0.0428	1302.552	0.2207	0.514	0.857	0.137
	5MA	0.7172	55.011	0.057	0.1321	805.41	0.159	0.627	0.636	0.104
Quadratic	Actual	0.358	101.512	0.0899	0.168	1214.43	0.1969	0.384	1.205	0.1668
	3MA	0.50377	75.6014	0.0739	0.518	599.602	0.111	0.671	0.7061	0.0858
	5MA	0.7751	49.059	0.047	0.706	332.939	0.062	0.783	0.485	0.069
Cubic	Actual	**0.534**	**86.457**	**0.075**	**0.169**	**1213.68**	**0.1977**	**0.433**	**1.157**	**0.158**
	3MA	**0.835**	**43.511**	**0.0399**	**0.559**	**573.644**	**0.109**	**0.716**	**0.654**	**0.082**
	5MA	**0.9271**	**27.949**	**0.0245**	**0.7066**	**332.937**	**0.062**	**0.875**	**0.368**	**0.0544**
Power	Actual	0.351	0.123	0.013	0.0315	0.252	0.024	0.287	0.214	0.111
	3MA	0.481	0.092	0.0114	0.1083	0.1717	0.0181	0.5068	0.1432	0.075
	5MA	0.724	0.0661	0.008	0.0717	0.1332	0.013	0.6045	0.114	0.061
Exponential	Actual	0.3501	0.1231	0.0135	0.0318	0.252	0.0248	0.288	0.213	0.1101
	3MA	0.48	0.0928	0.0114	0.1091	0.1716	0.0181	0.507	0.1431	0.0753
	5MA	0.724	0.0661	0.0082	0.0724	0.1331	0.0139	0.605	0.114	0.059

Table 4.3.11 showed that in area forecasting, the Cubic model was better than the others in terms of consistency. When applied to real data, it had R-square (0.534), RMSE (86.457), and MAPE (0.075). The model performance was also better with the use of moving averages, and the 3-year moving average obtained an R-square of 0.835, an RMSE of 43.511, and an MAPE of 0.0399. Best was with the 5-year moving average when R-square became 0.9271, RMSE decreased to 27.949, and MAPE decreased to as low as 0.0245. This indicates that the Cubic model, especially with added smoothing, is capable of explaining most of the variability in area and predicting with minimal error.

For predicting the production, the Cubic model proved more accurate once again. The actual values had an R-square of 0.169, RMSE of 1213.68, and MAPE of 0.1977. Applying a 3-year moving average, the values were improved to an R-square of 0.659, RMSE of 573.644, and MAPE of 0.109. The highest prediction was achieved by applying the 5-year moving average with R-square (0.7066), RMSE (332.937), and MAPE (0.062). The trend tells us that the forecasting power of the Cubic model is enhanced through smoothing and thus is extremely suitable for forecasting production.

Yield forecasting is also done similarly. The cubic model on actual values gave R-square of 0.433, RMSE of 1.157, and MAPE of 0.158. 3-year moving average reduced these to an R-square of 0.716, RMSE of 0.654, and MAPE of 0.082. The 5-year moving average gave a peak with an R-square of 0.875, RMSE of 0.368, and MAPE of 0.0544. These low error values and these high values of R-square confirm the competency of the Cubic model in yield prediction as well.

Generally, the verification process gives importance to the Cubic model, particularly when it is coupled with a 5-year moving average, because it is the most reliable and consistent means of forecasting the area, yield, and production of Urad. This combination not only minimizes the prediction errors but also maximizes the percentage of the variance explained, and hence it is appropriate for agriculture forecasting and planning.

Table 4.3.12 Validation of model performance for predicting area, production and yield of Pea

		Area			**Production**			**Yield**		
Model		R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**	R square	**RMSE**	**MAPE**
Linear	Actual	0.062	722.894	0.1616	0.071	11349.7	0.19787	0.041	1.586	0.113
	3MA	0.111	633.622	0.1415	0.1331	8552.39	0.1613	0.067	0.945	0.0668
	5MA	0.211	546.82	0.117	0.2188	7193.74	0.1236	0.0491	0.7615	0.056
Logarithmic	Actual	0.061	723.056	0.161	0.071	11352.6	0.1979	0.041	1.586	0.113
	3MA	0.111	633.797	0.1416	01323	8556.086	0.1614	0.0665	0.945	0.066
	5MA	0.211	547.009	0.1171	0.2179	7197.625	0.1237	0.0486	0.7917	0.0562
Quadratic	Actual	0.267	639.119	0.1383	0.2915	9915.236	0.1704	0.100	11352.57	0.197
	3MA	0.291	566.099	0.1311	0.291	9915.236	0.1704	0.1001	1.535	0.117
	5MA	0.341	499.98	0.116	0.484	6594.409	0.1269	0.399	0.757	0.0548
Cubic	Actual	**0.593**	**476.1**	**0.099**	**0.410**	**9042.268**	**0.154**	**0.131**	**1.509**	**0.1155**
	3MA	**0.764**	**326**	**0.0685**	**0.732**	**4754.89**	**0.0847**	**0.476**	**0.707**	**0.0491**
	5MA	**0.9016**	**193.14**	**0.0421**	**0.8691**	**2945.26**	**0.05319**	**0.539**	**0.551**	**0.041**
Power	Actual	0.062	0.181	0.019	0.093	0.241	0.0177	0.045	0.141	0.046
	3MA	0.1052	0.1565	0.0167	0.143	0.181	0.014	0.0799	0.0797	0.0271
	5MA	0.209	0.133	0.0139	0.231	0.147	0.011	0.0571	0.0655	0.0225
Exponential	Actual	0.063	0.1801	0.019	0.0943	0.241	0.017	0.045	0.141	0.046
	3MA	0.1057	0.1565	0.0167	0.943	0.241	0.0177	0.081	0.0796	0.0271
	5MA	0.2098	0.133	0.0139	0.144	0.181	0.01	0.057	0.0655	0.022

Table 4.3.12 indicates that in the area under pea production forecast, the Cubic model outperformed all the other models based on all data treatments. According to actual values, R-square of the Cubic model was 0.593, RMSE was 476.1, and MAPE was 0.099. The performance of the model was greatly enhanced when the moving averages were implemented, with R-square of 0.764, RMSE of 326, and MAPE of 0.0685 for the 3-year moving average, and an extremely high R-square of 0.9016, RMSE of 193.14, and MAPE of 0.0421 for the 5-year moving average. These findings support that the Cubic model, particularly with longer smoothing, is very good at forecasting area variance and making accurate forecasts with little error.

For forecasting production, the Cubic model worked best once more. With actual values, it gave an R-square value of 0.410, RMSE value of 9042.268, and MAPE value of 0.154. The forecast accuracy was even better using moving averages, and the 3-year moving average gave an R-square value of 0.732, RMSE value of 4754.89, and MAPE value of 0.0847. The optimal performance was noted with the 5-year moving average, and for it, the Cubic model noted R-square (0.8691), RMSE (2945.26), and MAPE (0.05319). The pattern indicates that the Cubic model, especially for the 5MA, is most well-suited to predict production with maximum variance explained and minimum prediction errors. The predictive yield also conformed to the same pattern, as the Cubic model produced the best values all the time.

On true values, the model achieved R-square (0.131), RMSE (1.509), and MAPE (0.1155). Even the use of moving averages fared better, with the 3MA having an R-square value of 0.476, an RMSE of 0.707, and an MAPE of 0.0491, while the 5MA had the highest R-square value of 0.539, the lowest RMSE value of 0.551, and the lowest MAPE of 0.041 amongst all the array of models and treatments. These results prove the Cubic model's ability to provide predictions, especially if data smoothing methods are used. In general, verification outcomes squarely validate the Cubic model, and overwhelmingly so when combined with a 5-year moving average, as the most precise and best method of estimating the area, production and yield of peas. The low error rates and high R-square values for all categories of prediction verify the practicability of the model to real-world agricultural planning and forecasting. The utilization of moving averages also increases model accuracy by removing the effect of short-run volatility, and thereby making more accurate and reliable predictions for policymakers.

4.4 Policy Recommendations based on findings of the study undertaken

This section displays policy suggestions based on results concerning pulse crop production trends, performances of statistical models, and decomposition analysis in the Mirzapur district of Uttar Pradesh. These suggestions are organized according to each precise study goal.

4.4.1 The production growth rate and trends of pulse crops in the Mirzapur district of Uttar Pradesh

Growth trend of pulse crops of Mirzapur district reflects that the area covered under pulses has gone down uniformly in the case of all the crops. From Table 4.1.1, Gram has recorded the highest negative linear growth rate (LGR) in area of -1.70%, followed by Urad -1.11% and Pea -0.56%. Similarly, Table 4.1.4 is also a witness to negative compound growth rate (CGR) of Gram (-1.63%), Urad (-1.07%), and Pea (-0.56%), and thus a long-term decline in cultivation area. These trends demand area enlargement-incentivizing policy by incentives, intercropping models, and input support to pulses.

At the production level, Table 4.1.2 indicates Gram (-1.09%), Arhar (-0.82%), and Pea (-0.80%) to be experiencing the decline in production further justified from CGR in Table 4.1.5 where Gram (-1.00%), Arhar (-0.79%), and Pea (-1.11%) are negative. It is owing to both the declining area as well as stable yield. Therefore, initiatives should be undertaken to provide support to the production with the release of high-yielding varieties, farm mechanization, and the adoption of scientific agronomic methods.

Conversely, Table 4.1.3 and Table 4.1.6 indicate a strong and positive rise in yield of Urad LGR (1.77%), CGR (1.64%), and Lentil LGR (0.81%), CGR (0.74%) that reflects high potential of the latter crops. Their consistent rise in yield on three and five-year moving averages justifies the need to expand their cultivation on large areas with technological intensification, improved seed availability, and farmers' training programs. Arhar, on the other hand, has negative growth in production, area, and yield (e.g., LGR in production: -0.82 in Table 4.1.2, CGR in area: -0.55% in Table 4.1.4), and low performance, which calls for cultivation of recovery varieties of drought, pest control operations, and extension advice in definite directions.

For the well-being of all the pulse crops in a pooled manner, market interventions such as smooth implementation of Minimum Support Prices (MSP), institutional credit schemes, and FPO support should be put into action. Rural storage investment, pulse processing facilities, and crop insurance programs will reduce risk and increase farmers' remuneration.

Finally, it is proposed to set up a district-level Pulse Monitoring and Research Cell for Mirzapur to monitor present data and implement adaptive policy, thus reactivating the production of pulses at the district level, so that it can ensure food security as well as economic stability for farmers.

4.4.2 Performance of various statistical models related to pulse crop production

The statistical model analysis of pulse crop in Mirzapur district indicated that the cubic regression model was the best among all three aspects: area, production and yield of the major pulses (Gram, Arhar, Lentil, Pea, and Urad). The field of the model was greatly improved with 3-year and 5-year moving averages, removing short-term volatility and emphasizing long-term trends. For example, Gram area had an R-square of 0.92 (actual) that increased to 0.98 (5MA) and 0.96 (3MA) in Table 4.2.1, and Arhar increased from 0.39 (actual), 0.80 (3MA), 0.95 (5MA); Table 4.2.4. Lentil (0.22 actual, 0.45 in 3MA, 0.76 in 5MA; Table 4.2.7). Pea and Urad also followed the same trends with high accuracy in smoothed data conditions (Tables 4.2.13 and 4.2.10). In production, the cubic model again emerged in the limelight, i.e., Gram production R-square rose from 0.51 (actual) to 0.63 (3MA) and 0.75 (5MA); Table 4.2.2, though less significant relative to matching gains in Arhar (0.31 to 0.57 to 0.71; Table 4.2.5), Lentil (0.18 to 0.45 to 0.76; Table 4.2.8), and Urad (0.16 to 0.55 to 0.70; Table 4.2.11).

For yield, Gram was enhanced from R-square raised from 0.32 (actual) to 0.58 (3MA) and 0.82 (5MA; Table 4.2.3); for Arhar, from 0.20 to 0.40 to 0.57 (Table 4.2.6); and for Lentil, to up to 0.82 in the 5MA scenario (Table 4.2.9). With each pulse, the cubic model yielded a better and equally stable fit, particularly when data were smoothed with 3-year and 5-year moving averages that suppressed the short-run oscillations and highlighted structural trends. The results concur with Sharma and Jain (2020) and previous researchers such as Ratkowsky (1990) and Bard (1974) on the use of nonlinear models and smoothing in crop data analysis. Policy-wise, the dominance of the cubic model makes it valuable as a trend predictor and planner of strategy. Policymakers can utilize such models in their input distribution, MSP revisions, infrastructural development, and diversification of crops, especially to revive the crops of Gram and Pea, and to consolidate gains in Lentil and Urad. The incorporation of these findings will lead to sustainable and evidence-based pulse production in the region.

4.4.3 Statistical coefficients and measures of pulse crop production, including decomposition analysis, and validate the selected models

The research encompassed an all-around analysis of key pulses like Gram, Arhar, Lentil, Pea, and Urad for area, production and yield of Mirzapur district through some basic statistical measures. The cubic regression model was best fitted to forecasting all the parameters, as it possessed the greatest R-square, with the minimum RMSE and MAPE errors in all the cases, especially when fitted against smoothed data sets by 3-year and 5-year moving averages. For instance, Gram area showed R-square improvement from 0.924 (actual) to 0.9866 (5MA), RMSE reducing from 673.209 to 240.371, and MAPE from 0.031 to 0.0109 (Table 4.3.8), while Lentil yield showed 0.827 R-square, 0.2393 RMSE, and 0.0252 MAPE using 5MA (Table 4.3.10). The results confirm the high quality of the model in nonlinear trend detection, hence its applicability for planning and forecasting purposes in the future. These results corroborate with Pooja *et al.* (2023) and Ray and Bhattacharyya (2020), who set the cubic model to most appropriately fit pulse production data.

For instance, the Instability index (Table 4.3.4) validated that Pea was most unstable by region (18.01% in total), Arhar (26.44%) and Urad (25.28%) by production, and Arhar (21.80%) and Urad (21.39%) by yield. Gram was the most stable crop in all dimensions. The percentage change (Table 4.3.7) showed that Gram experienced the highest declines in area (-29.40%) and production (-35.49%), whereas Arhar and Pea experienced negligible area improvements but production and yield losses. Conversely, Lentil experienced uniform area (4.80%), production (23.06%), and yield (17.43%) growth, and Urad experienced large yield (31.48%) growth despite an enormous area (-21.88%) decline. It is supported by Sharma *et al.* (2014) and Srivastava *et al.* (2013), who revealed declining trends for the conventional pulses such as Gram in the eastern parts of Uttar Pradesh, owing to decreased profitability and farmer preference.

Decomposition analysis (Table 4.3.5) indicated that Gram and Lentil had yield-driven growth and Arhar and Pea were area-driven but negatively affected by yield. Urad was an extreme situation where large area increases were offset by large yield decline and negative interaction. The mean decomposition (Table 4.3.6) validated the trends, showing Lentil and Urad as yield-dependent crops in the long term, Gram and Arhar as area-dependent, and Pea with poor but well-balanced contributions of both factors. This concurs with Kumar *et al*. (2018), Devi *et al*. (2017), and Balai *et al*. (2024), who also demonstrated area and yield-based tendencies of pulse crops at national and state levels. The results confirm that area growth shift to yield-led growth with stability-based interventions is necessary for sustainably viable pulse production in Mirzapur. Gram and Lentil, being yield-sensitive crops, need to be promoted with high-yielding stress-tolerant varieties and improved input management, while risky crops such as Arhar, Pea, and Urad need risk-reducing interventions by crop insurance, weather advisories, and improved agronomy. The cubic regression model, which is good as a forecaster, needs to be employed for procurement planning, MSP apportionment, and early warning. In Urad, where yield increase compensates area reduction, policies will have to focus on resource-saving intensification and not area increase. A policy approach yields stability and a model-based approach is needed for the maintenance and production of pulses in the district.

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Chapter 5

SUMMARY AND CONCLUSION

This chapter provides a brief outline of the summary and conclusion of the work done in the previous chapters.

5.1 Summary

- In **Chapter 1**, a brief introduction to the pulse production in the Mirzapur district of Uttar Pradesh has been provided, along with the objectives of the present investigation.
- In **Chapter 2**, a detailed review of the literature on pulse crops has been elaborated.
- In **Chapter 3**, the source of data, along with the statistical measures and models utilized for the analysis, has been described.
- In **Chapter 4**, the time series data analysis of pulse production in Mirzapur district of Uttar Pradesh. viz., Gram, Arhar, Lentil, Urad and Pea have been carried out. Furthermore, the findings of the statistical analyses have been presented.

The findings of the investigation are summarized pointwise below as per the statistical analysis carried out under the study:

5.1.1 To demonstrate the production growth rate and trends of pulse crops in the Mirzapur district of Uttar Pradesh.

The trend analysis and growth rate of the five major pulses Gram, Arhar, Lentil, Pea, and Urad in Mirzapur, showed a uniform decline in area in all of these crops, most vital in Gram (-1.70% LGR; -1.63% CGR) and Urad (-1.11% LGR; -1.07% CGR), while Lentil was almost at equilibrium (Table 4.1.1 & 4.1.4). Production declined in Gram, Arhar, and Pea, but increased in Lentil (0.78% LGR; 0.65% CGR) and Urad (0.73% LGR; 0.55% CGR), reflecting the implementation of better practices (Table 4.1.2 & 4.1.5). Yield trends were encouraging for Urad (1.77% LGR; 1.64% CGR), Lentil and Gram, but continued to be declining in Arhar and Pea (Table 4.1.3 & 4.1.6). Overall, the pulse sector has to battle structural land contraction, production setback in Gram, Arhar and Pea, but spurring yield increases in Lentil and Urad. These need area stabilization, improvement in varieties, and price support for declining crops, and consolidation of yield increases in Lentil and Urad.

These results register a structural realignment of pulse cultivation in the region because of market forces, profitability, and agro-climatic sensitivity. The trends concur with those of Sharma *et al*. (2014) and Srivastava *et al*. (2013), who found trends about trend parallelism in pulses in Eastern Uttar Pradesh.

5.1.2 To implement and assess the performance of various statistical models related to pulse crop production.

To evaluate pulse crop dynamics, six functional forms linear, logarithmic, quadratic, exponential, power, and cubic regression models were applied to the time-series data on area, production, and yield of each of the crops. The most appropriate among these was the cubic regression model with the best fit across all variables and smoothing conditions (actual, 3-year, and 5-year moving averages). The model worked especially well in detecting nonlinear and structural trends of crop behavior over time. For example, under the 5-year moving average, the cubic model graphically tracked the turning points and curvature in Gram, Arhar, and Lentil crop area and yield trends. This performance aligns with previous research by Pooja *et al*. (2023) and Ray and Bhattacharyya (2020), who established the cubic model as highly suitable for pulse data due to its ability to model complexity and seasonal reversals in agriculture.

5.1.3 To analyze the statistical coefficients and measures of pulse crop production, including decomposition analysis and validate the selected models.

This objective integrates model validation, decomposition analysis, instability, and percentage change. Model validation based on statistical measures like R^2, RMSE, and MAPE validated the performance advantage of the cubic regression model for all pulse types. For instance, Gram area under the cubic model recorded R^2 (0.9866), and Lentil yield R^2 (0.827), with the lowest values for RMSE and MAPE within smoothed datasets (Tables 4.3.8 & 4.3.10). The instability index (Table 4.3.4) validated that Pea was the most unstable by area (18.01% in total), Arhar (26.44%), and Urad (25.28%) by production and yield (21.80% and 21.39% respectively). Gram proved to be the stable crop by dimensions. The decomposition (Table 4.3.5) revealed that Gram production growth was yield-led (yield effect 82.84%) as was that of Lentil (yield effect 20.80%), while Arhar (120.22%) and Pea (161.14%) were area-led but hampered by adverse yield effects. Urad was a special case, even with massive area increases, steep yield fall, and negative interaction, which negated the advantage. Mean decomposition (Table 4.3.6) also made it clear that Lentil (yield effect 727.64%) and Urad (yield effect 352.64%) were yield-oriented long-term crops, whereas Gram (area effect 149.63%) and Arhar (area effect 72.91%) were area-oriented. Pea exhibited balanced but weak contributions (area 90.89%, yield 10.95%). Percentage change (Table 4.3.7) indicated that Gram had the sharpest fall in area (-29.40%) and production (-35.49%), although yield was high momentarily in five-year MA (20.78%). Arhar experienced marginal long-term area increase (2.93%) but production and yield declines. Pea increased in area (7.06%) but decreased in production and yield. By contrast, Lentil showed consistent positive growth in area (4.80%), production (23.06%), and yield (17.43%), while Urad also achieved strong yield gains and modest production growth despite a sharp fall in area. These results are consistent with findings by Kumar *et al*. (2018) and Devi *et al*. (2017) on decomposition and Kumari and Malik (2023) on yield stability across Indian pulses.

5.1.4 To propose policy recommendations informed by the outcomes of the analyzed statistical models.

Mirzapur pulse crop survey indicates the necessity of evidence-based and crop-centric policies. Gram and Urad experienced bitter area reductions, while Gram, Arhar, and Pea experienced production reductions as well, revealing the necessity for stabilizing area through land use planning, cultivation incentives, and guaranteed MSP. Whereas, Urad and Lentil had yield-driven growth, and thus carry the potential to be technology spread industry leader crops, seed replacement, management improvement, and input support. Pea and Arhar were area-driven but with poor yields, and thus need work at area protection as well as improvement in yields through varietal improvement and better agronomy. Examination of instability identified Pea and Arhar as very unstable and Urad with yield instability, to which storage, crop insurance, and climate-resilient measures are recommended. Gram, being relatively stable, can be enhanced by long-term productivity programs and market intervention. Verification of the model rationalized the superiority of cubic regression in a model of nonlinear trends and ease of policy planning through data. In all, policy will need to adopt a twofold approach, rejuvenating such sick crops as Gram, Arhar, and Pea through stabilizing land and production, and improving yield-based crops like Lentil and Urad through technology, extension, and input subsidy, for the sake of promoting healthy and remunerative pulses' production in Mirzapur. This objective reinforces the importance of data-driven, crop-specific strategies, as echoed in the works of Singh and Bansal (2020) and More *et al*. (2015).

5.2 Conclusion

The research concludes that pulse farming in Mirzapur is experiencing a structural adjustment with an overall area shrinkage, decline in production in Gram, Arhar, and Pea, and concurrent yield-driven expansion in Lentil and Urad. The dominance of the cubic regression model in capturing nonlinear and structural patterns proves its usefulness for analyzing and projecting pulse crop dynamics. Decomposition analysis also indicated that Lentil and Urad are yield-driven crops, whereas Gram and Arhar are area-dependent, and Pea had weak and unstable contributions of both dimensions. Instability analysis identified Pea and Arhar as the most unstable crops, while Gram was comparatively stable. These observations highlight the necessity of a twofold policy strategy: stabilizing production and land in falling crops such as Gram, Arhar, and Pea under MSP, varietal development, and land-use planning, whereas solidifying the yield-led growth of Lentil and Urad under technology transfer, input subsidy, and extension services. Therefore, the research enhances the role of implementing evidence-based, crop-specific, and data-driven policies for ensuring remunerative and sustainable pulse cultivation in Mirzapur district.

5.3 Suggestion

The research suggests that stabilization of pulse areas, especially Gram, Arhar, and Pea, must be ensured through land-use planning, intercropping, and diversification. Instability and yield loss in Arhar, Pea, and Urad require development and dissemination of high-yielding climate-resistant varieties and timely replacement of seed. For farmers' interest, more market and price support in the form of MSP guarantee, procurement, and better marketing channels needs to be assured. Pea and Urad, which are under yield-driven growth, need emphasis on higher agronomics, proper input use, and mechanization under credit and subsidy policy. Volatility in Pea, Arhar, and Urad needs to be countered through risk management by crop insurance, warehousing facilities, and climatic resilience. Cubic regression certification attests that complex models are required in policy-making; therefore, additional research has to incorporate climate, soil, and price data for additional projections. Institutional development of farmer organizations such as FPOs and cooperatives can be an effective tool of promoting collective bargaining, cost reduction, and remunerative and sustainable pulse cultivation in Mirzapur.

5.3 Future Scope of Research

The present study provides important insights into the growth, instability and decomposition of major pulse crops in Mirzapur but opens doors for further studies. The follow-up studies can incorporate district-level climatic heterogeneity, soil fertility levels, and rainfall distribution to pinpoint accurately agro-climatic determinants of pulse performance. Incorporation of farmers' socio-economy level, pattern of adoption, and resource constraints will enable us to perceive the dynamics of production in a more realistic sense. Advanced time-series and econometric techniques like ARIMA, VAR, and machine learning can be used in more precise forecasting and policy analysis. Cross-district or cross-state comparison would also enhance generalizability of findings and measurement of regional pulse culture strengths and weaknesses. In addition to these, the influence of institutional drivers like FPOs, cooperatives, and the role of government programs in returns to production must be investigated further. Thus, subsequent research has to be interdisciplinary within the domain of a combination of biophysical, economic, and policy frameworks so that more efficient pulse development strategies for sustainability could be formulated.

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LITERATURE CITED

Ardeshna, N. J. and Shiyani, R. L., 2011. "Spatio-temporal growth performance of pulses: a case of Gujarat". *Economic Affairs (Calcutta),* 56(1):85-97.

Ansari, S., Ali, N. and Rashid, M. 2022. Growth and instability of pulses production in Uttar Pradesh: A decomposition analysis. *Asian Journal of Multidimensional Research,* 11(1): 71-81.

Agricultural Department, U.P., India. (*https://upagripardarshi.gov.in/Index.aspx*)

Armstrong, J.S. 1985. Long-Range Forecasting: From Crystal Ball to Computer. Wiley.

Bard, Y. 1974. Nonlinear parameter estimation. Academic Press.

Balai, H. K., Meena, P. C., Meena, M. L., Bairwa, K. C., Kumar, S., Meena, R. P. and Bairwa, S. K. 2024. Growth, Decomposition and Instability Analysis of Major Rabi Pulse Crops in Madhya Pradesh, India. *Asian Journal of Agricultural Extension, Economics & Sociology*, 42(7), 79-88.

Bisht, A. and Kumar, A. 2018. Growth and instability analysis of pulses production in India. *International Journal of Agriculture Sciences*, 10(14), 0975–3710.

Bhavya, N., Rao, V. S., Umar, S. N., and Radha, Y. 2018. Trends in Area, Production and Productivity of Chickpea in Prakasam District. *The Andhra Agricultural Journal* 65(1): 245-249.

Cuddy, J.D.A. and Della Valle, P. A. 1978. Measuring the instability of time series data. *Oxford Bulletin of Economics and Statistics,* 40(1): 79-85.

Chatterjee, S., Nath, R., Ray, J., Ray, M., Gunri, S. K. and Bandopadhyay, P. 2014. Analysis of pulse production in major states of India. *Journal of Food Legumes*, 27(2), 140-145.

Changela, P. and Devi, G. 2018. Estimating growth rates and decomposition analysis of major pulses in Gujarat. *Journal of Plant Development Sciences*, 10(12), 689-693.

Devegowda, SR., Singh, OP. and Kumari, K. 2018. Growth performance of pulses in India.

The Pharma Innovation Journal, 7(11), 394–399.

Devi, Y.L., Arivelarasan, T. and Kapngaihlian, J. 2017. Pulses production in India: Trend and decomposition analysis. *Economic Affairs*, 62(3), 435-438.

Devi, M., & Mehla, V. 2022. Trends and Growth Pattern of Major Pulses Crops in India. *International Journal of Education and Management Studies*, 12(2), 84-86.

District Mirzapur, Uttar Pradesh Website (*https://mirzapur.nic.in/*)

District Profile, Mirzapur, U.P., (Ministry of MSME, Govt. of India) (*https://dcmsme.gov.in/dips/DIP%20Mirzapur%20corrected.pdf*)

Fisher, R.A. 1925. Statistical Methods for Research Workers. Oliver and Boyd.

Gajbhiye, S., Wankhade, R. N. and Kakde, S. J., 2010, "Growth and instability of chickpea production in Vidarbha region of Maharashtra", International Journal of Commerce and Business Management, 3(2):172-174.

Gupta, S.C. & Kapoor, V.K. 2022. Fundamentals of Mathematical Statistics. 12th ed. New Delhi, Sultan Chand & Sons. 1460p.

Gauss, C.F. 1809. Theoria motus corporum coelestium in sectionibus conicis solem ambientium [Theory of the Motion of the Heavenly Bodies Moving about the Sun in Conic Sections].

Gauss, C.F. and Legendre, A.M. 1805. Nouvelles méthodes pour la détermination des orbites des comètes [New Methods for Determining the Orbits of Comets].

Galton, F. (1886). Regression towards mediocrity in hereditary stature. *Journal of the Anthropological Institute of Great Britain and Ireland,* 15, 246–263.

Hasan, R. and Khan, D.N. 2018. Diagnosing pulse production and consumption in Uttar Pradesh: an inter-regional analysis. *Int J Curr Microbiol App Sci*, 7(7), 860-5.

India. ICAR-Indian Institute of Pulses Research, Kanpur Uttar Pradesh. (*https://iipr.icar.gov.in/*)

Kumari, N. and Malik, DP. 2023. Status, growth, and variability of pulses in India. *The Pharma Innovation Journal,* 12(5), 2920-2928.

Kumar, H., Bhatt, S. and Kumar, R. 2018. Growth and decomposition analysis of pulses production in India. *Journal of Food Legumes*, 31(2), 114-116.

Krishi Vigyan Kendra, Mirzapur, **District Profile.** (*https://mirzapur.kvk4.in/*)

Kalia, A. and Mishra, S. 2017. Supply response of arhar in Allahabad and Mirzapur districts of Uttar Pradesh. *Progressive Research – An International Journal,*12 (Special-II), 1946-1948.

India. Ministry of Agriculture & Farmers Welfare. Directorate of Economics & Statistics, DAC&FW, New Delhi, Govt. of India. (*https://desagri.gov.in/*)

Map of Uttar Pradesh, India (*https://www.mapsofindia.com/uttar-pradesh/*)

Map of Mirzapur District, Uttar Pradesh (*https://www.mapsofindia.com/maps/uttarpradesh/districts/mirzapur.htm*)

More, S.S., Singh, N. and Kuthe, S.B. 2015. Performance of pulses crops in Gujarat state - a decomposition analysis. *International Journal of Agriculture Sciences,* 7, 510-515.

Minhas, B. S. and Vaidyanathan, A. (1965). Growth of crop output in India, 1951–54 to 1958–61: An analysis by component elements. *Journal of the Indian Society of Agricultural Statistics,* 17(2), 230–252.

Malthus, T.R. 1798. An Essay on the Principle of Population. J. Johnson.

Narayan, P. and Kumar, S. 2015. Constraints of growth in area production and productivity of pulses in India: An analytical approach to major pulses. *Indian Journal of Agricultural Research*, 49(2), 114-124.

Napier, J. (1614). Mirifici logarithmorum canonis descriptio. Edinburgh: Andrew Hart.

Pearson, K. 1895. Note on regression and inheritance in the case of two parents. Proceedings of the Royal Society of London, 58: 240-242.

Pandey, E., Mishra, P., Mehta, V., Karakaya, K. and Abotaleb, M. 2021. Growth Rate of Pulses in Eastern Uttar Pradesh: a Zone-wise Analysis. Economic Affairs, 66(3), 377-382.

Pooja, Mehta, V., Kumar, S. and Kushwaha, R. R. 2023. Regression models for furcating pulses area and production in India. *International Journal of Statistics and Applied Mathematics;* 8(5), 109-115.

Ray. S. and Bhattacharyya, B. 2020. Time series modeling and forecasting on pulses. production behavior of India. *Indian Journal of Ecology,* 47(4): 1140-1149.

Rani, R., Sah, U., Kumar, H., Bishnoi, R., Ojha, J. and Katiyar, M. 2023. Mungbean in Rajasthan: Growth performance and decomposition analysis. *Journal of Food Legumes,* 36(1): 78-83.

Ratkowsky, D. A. 1990. Handbook of Nonlinear Regression Models. CRC Press.

Singh, G. and Usmani, R. A. 2024. Decomposition of production growth and identification of efficient cropping zones for major pulse crops in Uttar Pradesh and Uttarakhand. *Journal of Food Legumes*, 37(2), 196-204.

Singh, G. and Usmani, R. A. 2024. Growth and Instability of Pulses in Uttar Pradesh and Uttarakhand. *Economic Affairs*, 69(2), 903-907.

Singh, L. and Bansal, S. 2020. Pulses in Punjab: growth rate and decomposition analysis. *International Journal of Farm Sciences,* 10(2), 81-85.

Sah, U., Dixit, G. P., Kumar, H., Ojha, J., Katiyar, M., Singh, V., Dubey, S.K. and Singh, N. P. 2021. Dynamics of pulse scenario in Bundelkhand region of Uttar Pradesh: A temporal analysis. *Indian Journal of Extension Education,* 57(4), 97-103.

Sharad Sachan, S.S., Sneha Choudhary, S.C. and Singh, H.L. 2018. Regional growth analysis of pulses production in Uttar Pradesh, India. *Plant Archives* 18 (1), 291-296.

Sharma, H., & Jain, N. 2020. Statistical evaluation of forecasting techniques in agricultural time series data. Journal of Agricultural Statistics and Informatics, 12(2), 87-95.

Sharma, M.K., Sisodia, B.V.S. and Lal, K. 2013. Growth and Trends of Pulse Production in India. *Journal of Food Legumes,*26(1,2), 86-92.

Sharma, M.K., Sisodia, B.V.S. and Kumar, V. 2014. The pattern of growth and scenario of pulse production in Uttar Pradesh: A regional study. *International Journal of Innovative Social Science & Humanities Research*, 2, 1–16.

Srivastava, S.C., Singh, B.K., Tomar, S.S. and Yadava, H.S. 2013**.** Growth pattern of major pulses in eastern Uttar Pradesh. *International Journal of Farm Sciences*, 3(2), 1-9.

***Sankhikiya Patrika* (Statistical Bulletin) published by the Economics and Statistics Division, Planning Department, Government of Uttar Pradesh.** (*https://updes.up.nic.in/spideradmin/Hpage1.jsp*)

Salunkhe, S.V., Pokharkar, V.G. and Gulave, C.M. 2021. Growth and instability of area, production and productivity of chickpea in Maharashtra. *Journal of Pharmacognosy and Phytochemistry,* 10: 198-201.

Zaremba, L. 1978. Mathematical Models in Economic Time Series Analysis. Polish Scientific Publishers.

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APPENDIX

Time series data on area, production, and yield of the Gram crop of Mirzapur district of Uttar Pradesh

Overall-year			
YEAR	**A**	**P**	**Y**
1994	19644	273890	13.94
1995	20297	225650	11.12
1996	19640	186730	9.51
1997	19944	177900	8.92
1998	18714	143930	7.69
1999	17662	159180	9.01
2000	15735	163680	10.40
2001	15778	134920	8.55
2002	17396	161280	9.27
2003	17815	192420	10.80
2004	16853	189340	11.23
2005	14864	145170	9.77
2006	15082	126010	8.35
2007	14980	164720	11.00
2008	14223	126050	8.86
2009	13965	132800	9.51
2010	13831	126210	9.13
2011	13633	141700	10.39
2012	13446	143620	10.68
2013	13382	151180	11.30
2014	13026	134400	10.32
2015	12259	132780	10.83
2016	12458	102240	8.21
2017	13382	153660	11.48
2018	13800	195580	14.17
2019	12817	162240	12.66
2020	13313	112660	8.46
2021	13676	188470	13.78
2022	13868	176680	12.74

Three-year moving average			
YEAR	**A**	**P**	**Y**
1996	19860	228757	11.52
1997	19960	196760	9.86
1998	19433	169520	8.72
1999	18773	160337	8.54
2000	17370	155597	8.96
2001	16392	152593	9.31
2002	16303	153293	9.40
2003	16996	162873	9.58
2004	17355	181013	10.43
2005	16511	175643	10.64
2006	15600	153507	9.84
2007	14975	145300	9.70
2008	14762	138927	9.41
2009	14389	141190	9.81
2010	14006	128353	9.16
2011	13810	133570	9.67
2012	13637	137177	10.06
2013	13487	145500	10.79
2014	13285	143067	10.77
2015	12889	139453	10.82
2016	12581	123140	9.79
2017	12700	129560	10.20
2018	13213	150493	11.39
2019	13333	170493	12.79
2020	13310	156827	11.78
2021	13269	154457	11.64
2022	13619	159270	11.69

Five-year moving average			
YEAR	**A**	**P**	**Y**
1998	19648	201620	10.26
1999	19251	178678	9.28
2000	18339	166284	9.07
2001	17567	155922	8.88
2002	17057	152598	8.95
2003	16877	162296	9.62
2004	16715	168328	10.07
2005	16541	164626	9.95
2006	16402	162844	9.93
2007	15919	163532	10.27
2008	15200	150258	9.89
2009	14623	138950	9.50
2010	14416	135158	9.38
2011	14126	138296	9.79
2012	13820	134076	9.70
2013	13651	139102	10.19
2014	13464	139422	10.36
2015	13149	140736	10.70
2016	12914	132844	10.29
2017	12901	134852	10.45
2018	12985	143732	11.07
2019	12943	149300	11.54
2020	13154	145276	11.04
2021	13398	162522	12.13
2022	13495	167126	12.38

Time series data on area, production, and yield of the Arhar crop of Mirzapur district of Uttar Pradesh

Overall-year			
YEAR	A	P	Y
1994	15532	182550	11.75
1995	15110	150470	9.96
1996	15254	180190	11.81
1997	14389	142080	9.87
1998	13899	84610	6.09
1999	14795	183730	12.42
2000	13783	154270	11.19
2001	13449	119890	8.91
2002	14065	152110	10.81
2003	12718	117080	9.21
2004	13576	142020	10.46
2005	13827	92180	6.67
2006	13264	84380	6.36
2007	13247	102480	7.74
2008	13029	85550	6.57
2009	12547	111150	8.86
2010	13257	50750	3.83
2011	12888	110480	8.57
2012	12967	128820	9.93
2013	12893	130560	10.13
2014	12501	124220	9.94
2015	12591	107980	8.58
2016	10868	85540	7.87
2017	16096	195910	12.17
2018	12427	140620	11.32
2019	11124	116250	10.45
2020	12172	86190	7.08
2021	12698	130420	10.27
2022	15987	160030	10.01

Three-year moving average			
YEAR	A	P	Y
1996	15299	171070	11.18
1997	14918	157580	10.56
1998	14514	135627	9.34
1999	14361	136807	9.53
2000	14159	140870	9.95
2001	14009	152630	10.90
2002	13766	142090	10.32
2003	13411	129693	9.67
2004	13453	137070	10.19
2005	13374	117093	8.76
2006	13556	106193	7.83
2007	13446	93013	6.92
2008	13180	90803	6.89
2009	12941	99727	7.71
2010	12944	82483	6.37
2011	12897	90793	7.04
2012	13037	96683	7.42
2013	12916	123287	9.55
2014	12787	127867	10.00
2015	12662	120920	9.55
2016	11987	105913	8.84
2017	13185	129810	9.85
2018	13130	140690	10.71
2019	13216	150927	11.42
2020	11908	114353	9.60
2021	11998	110953	9.25
2022	13619	125547	9.22

Five-year moving average			
YEAR	A	P	Y
1998	14837	147980	9.97
1999	14689	148216	10.09
2000	14424	148976	10.33
2001	14063	136916	9.74
2002	13998	138922	9.92
2003	13762	145416	10.57
2004	13518	137074	10.14
2005	13527	124656	9.22
2006	13490	117554	8.71
2007	13326	107628	8.08
2008	13389	101322	7.57
2009	13183	95148	7.22
2010	13069	86862	6.65
2011	12994	92082	7.09
2012	12938	97350	7.52
2013	12910	106352	8.24
2014	12901	108966	8.45
2015	12768	120412	9.43
2016	12364	115424	9.34
2017	12990	128842	9.92
2018	12897	130854	10.15
2019	12621	129260	10.24
2020	12537	124902	9.96
2021	12903	133878	10.38
2022	12882	126702	9.84

Time series data on area, production, and yield of the Lentil crop of Mirzapur district of Uttar Pradesh

Overall-year			
YEAR	**A**	**P**	**Y**
1994	5315	41190	7.75
1995	5011	32830	6.55
1996	5261	34070	6.48
1997	4887	31870	6.52
1998	4741	32000	6.75
1999	5044	42070	8.34
2000	4894	34600	7.07
2001	4904	37910	7.73
2002	6239	53840	8.63
2003	6465	53140	8.22
2004	7223	59590	8.25
2005	5906	43590	7.38
2006	6116	39390	6.44
2007	6057	49180	8.12
2008	5745	38610	6.72
2009	5096	39290	7.71
2010	5030	41300	8.21
2011	4958	30640	6.18
2012	5012	48220	9.62
2013	5064	43150	8.52
2014	3936	27360	6.95
2015	4204	33840	8.05
2016	4091	26510	6.48
2017	5097	45210	8.87
2018	4678	48980	10.47
2019	7297	75670	10.37
2020	5542	33580	6.06
2021	5606	52190	9.31
2022	5570	50690	9.10

Three-year moving average			
YEAR	**A**	**P**	**Y**
1996	5196	36030	6.93
1997	5053	32923	6.52
1998	4963	32647	6.58
1999	4891	35313	7.22
2000	4893	36223	7.40
2001	4947	38193	7.72
2002	5346	42117	7.88
2003	5869	48297	8.23
2004	6642	55523	8.36
2005	6531	52107	7.98
2006	6415	47523	7.41
2007	6026	44053	7.31
2008	5973	42393	7.10
2009	5633	42360	7.52
2010	5290	39733	7.51
2011	5028	37077	7.37
2012	5000	40053	8.01
2013	5011	40670	8.12
2014	4671	39577	8.47
2015	4401	34783	7.90
2016	4077	29237	7.17
2017	4464	35187	7.88
2018	4622	40233	8.70
2019	5691	56620	9.95
2020	5839	52743	9.03
2021	6148	53813	8.75
2022	5573	45487	8.16

Five-year moving average			
YEAR	**A**	**P**	**Y**
1998	5043	34392	6.82
1999	4989	34568	6.93
2000	4965	34922	7.03
2001	4894	35690	7.29
2002	5164	40084	7.76
2003	5509	44312	8.04
2004	5945	47816	8.04
2005	6147	49614	8.07
2006	6390	49910	7.81
2007	6353	48978	7.71
2008	6209	46072	7.42
2009	5784	42012	7.26
2010	5609	41554	7.41
2011	5377	39804	7.40
2012	5168	39612	7.66
2013	5032	40520	8.05
2014	4800	38134	7.94
2015	4635	36642	7.91
2016	4461	35816	8.03
2017	4478	35214	7.86
2018	4401	36380	8.27
2019	5073	46042	9.08
2020	5341	45990	8.61
2021	5644	51126	9.06
2022	5739	52222	9.10

Time series data on area, production, and yield of the Urad crop of Mirzapur district of Uttar Pradesh

Overall-year			
YEAR	**A**	**P**	**Y**
1994	928	5150	5.55
1995	810	3860	4.77
1996	660	3610	5.47
1997	912	4860	5.33
1998	1079	6310	5.85
1999	1025	4210	4.11
2000	1004	5450	5.43
2001	1016	5140	5.06
2002	921	3560	3.87
2003	781	2770	3.55
2004	821	5150	6.27
2005	863	3200	3.71
2006	807	3310	4.10
2007	824	4100	4.98
2008	783	3720	4.75
2009	696	3630	5.22
2010	706	3240	4.59
2011	688	3960	5.76
2012	700	4220	6.03
2013	672	5650	8.41
2014	678	5910	8.72
2015	687	5000	7.28
2016	708	3310	4.68
2017	740	4100	5.54
2018	632	4310	6.82
2019	707	5430	7.68
2020	966	9690	10.03
2021	690	3750	5.43
2022	725	5290	7.30

Three-year moving average			
YEAR	**A**	**P**	**Y**
1996	799	4207	5.26
1997	794	4110	5.18
1998	884	4927	5.58
1999	1005	5127	5.10
2000	1036	5323	5.14
2001	1015	4933	4.86
2002	980	4717	4.81
2003	906	3823	4.22
2004	841	3827	4.55
2005	822	3707	4.51
2006	830	3887	4.68
2007	831	3537	4.25
2008	805	3710	4.61
2009	768	3817	4.97
2010	728	3530	4.85
2011	697	3610	5.18
2012	698	3807	5.45
2013	687	4610	6.71
2014	683	5260	7.70
2015	679	5520	8.13
2016	691	4740	6.86
2017	712	4137	5.81
2018	693	3907	5.63
2019	693	4613	6.66
2020	768	6477	8.43
2021	788	6290	7.99
2022	794	6243	7.87

Five-year moving average			
YEAR	**A**	**P**	**Y**
1998	878	4758	5.42
1999	897	4570	5.09
2000	936	4888	5.22
2001	1007	5194	5.16
2002	1009	4934	4.89
2003	949	4226	4.45
2004	909	4414	4.86
2005	880	3964	4.50
2006	839	3598	4.29
2007	819	3706	4.52
2008	820	3896	4.75
2009	795	3592	4.52
2010	763	3600	4.72
2011	739	3730	5.04
2012	715	3754	5.25
2013	692	4140	5.98
2014	689	4596	6.67
2015	685	4948	7.22
2016	689	4818	6.99
2017	697	4794	6.88
2018	689	4526	6.57
2019	695	4430	6.38
2020	751	5368	7.15
2021	747	5456	7.30
2022	744	5694	7.65

Time series data on area, production, and yield of the Pea crop of Mirzapur district of Uttar Pradesh

Overall-year			
YEAR	**A**	**P**	**Y**
1994	3256	43530	13.37
1995	3132	39500	12.61
1996	3283	33490	10.20
1997	3583	44960	12.55
1998	3818	49600	12.99
1999	4247	44850	10.56
2000	4627	47980	10.37
2001	4841	57560	11.89
2002	5137	65290	12.71
2003	5102	48520	9.51
2004	5432	78380	14.43
2005	4724	51070	10.81
2006	4817	54670	11.35
2007	4705	63560	13.51
2008	4464	63210	14.16
2009	4041	52130	12.90
2010	3789	49860	13.16
2011	3379	45790	13.55
2012	3239	38800	11.98
2013	3145	45890	14.59
2014	3102	35020	11.29
2015	3583	33430	9.33
2016	2878	28000	9.73
2017	3866	46160	11.94
2018	3878	44360	11.44
2019	4965	63250	12.74
2020	3319	25790	7.77
2021	3063	35220	11.50
2022	3486	39290	11.27

Three-year moving average			
YEAR	**A**	**P**	**Y**
1996	3224	38840	12.05
1997	3333	39317	11.80
1998	3561	42683	11.99
1999	3883	46470	11.97
2000	4231	47477	11.22
2001	4572	50130	10.97
2002	4868	56943	11.70
2003	5027	57123	11.36
2004	5224	64063	12.26
2005	5086	59323	11.66
2006	4991	61373	12.30
2007	4749	56433	11.88
2008	4662	60480	12.97
2009	4403	59633	13.54
2010	4098	55067	13.44
2011	3736	49260	13.18
2012	3469	44817	12.92
2013	3254	43493	13.36
2014	3162	39903	12.62
2015	3277	38113	11.63
2016	3188	32150	10.09
2017	3442	35863	10.42
2018	3541	39507	11.16
2019	4236	51257	12.10
2020	4054	44467	10.97
2021	3782	41420	10.95
2022	3289	33433	10.16

Five-year moving average			
YEAR	**A**	**P**	**Y**
1998	3414	42216	12.36
1999	3613	42480	11.76
2000	3912	44176	11.29
2001	4223	48990	11.60
2002	4534	53056	11.70
2003	4791	52840	11.03
2004	5028	59546	11.84
2005	5047	60164	11.92
2006	5042	59586	11.82
2007	4956	59240	11.95
2008	4828	62178	12.88
2009	4550	56928	12.51
2010	4363	56686	12.99
2011	4076	54910	13.47
2012	3782	49958	13.21
2013	3519	46494	13.21
2014	3331	43072	12.93
2015	3290	39786	12.09
2016	3189	36228	11.36
2017	3315	37700	11.37
2018	3461	37394	10.80
2019	3834	43040	11.23
2020	3781	41512	10.98
2021	3818	42956	11.25
2022	3742	41582	11.11

Note: A = Area (in Hectares), P = Production (in Quintal), and Y = Yield (in Quintal / Hectare)

Sources: *Sankhikiya Patrika* (Statistical Bulletin) published by the Economics and Statistics Division, Planning Department, Government of Uttar Pradesh, and DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India.

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ABSTRACT

The research critically analyzed the growth performance and trends of important pulse crops (Arhar, Gram, Pea, Lentil and Urad) of Mirzapur district of Uttar Pradesh for 1993–94 to 2021–22 using secondary time-series data. Linear and compound growth rates (LGR & CGR) indicated a consistent decline in area and production in Arhar, Gram, and Pea, whereas Gram declined sharply, whereas Lentil and Urad exhibited consistent positive growth in production and yield, of which the highest growth in yield exhibited by Urad. Of all statistical models attempted linear, logarithmic, quadratic, cubic, exponential, and power. The cubic regression model was the strongest and most fit in all the parameters (R^2, RMSE and MAPE) for area, production and yield series, especially when smoothed using three-year and five-year moving averages. Significantly, the cubic model demonstrated superior explanatory capacity and forecasting precision in identifying the long-term trend of pulse cultivation, especially for Gram, Lentil, and Urad. The report indicates severe structural decay in crops like Gram and Pea, which requires measures such as improved seed technology, assured procurement, and input subsidies. While that would be needed to maintain the gains in Lentil and Urad as well, the latter two are not showing "alarming" trends. The study emphasizes the need to apply advanced smoothing techniques and higher-order polynomials for modeling the agricultural time-series data in the interests of policy making, yield forecasting and strategic planning for sustainable pulse cultivation in the region.

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शोध प्रबंध का शीर्षक : "भारत के उत्तर प्रदेश के मीरजापुर जिले में दाल उत्पादन की प्रवृत्ति , वृद्धि और स्थिरता पर एक अध्ययन"

सलाहकार : डॉ. पीयूष कुमार सिंह , सहायक प्राध्यापक एवं प्रभारी, कृषि सांख्यिकी विभाग

सारांश

अनुसंधान में द्वितीयक समय-श्रृंखला डेटा का उपयोग करके 1993-94 से 2021-22 के लिए उत्तर प्रदेश के मीरजापुर जिले के महत्वपूर्ण दलहनी फसलों (अरहर, चना, मटर, मसूर और उड़द) के विकास प्रदर्शन और रुझानों का गंभीर विश्लेषण किया गया। रैखिक और चक्रवृद्धि वृद्धि दर (एलजीआर और सीजीआर) ने अरहर, चना और मटर के क्षेत्र और उत्पादन में लगातार गिरावट का संकेत दिया, जबकि चना में तेजी से गिरावट आई, जबकि मसूर और उड़द ने उत्पादन और उपज में लगातार सकारात्मक वृद्धि का प्रदर्शन किया, जिसमें से उड़द द्वारा प्रदर्शित उपज में सबसे अधिक वृद्धि हुई। सभी सांख्यिकीय मॉडलों रैखिक, लघुगणकीय, द्विघात, घन, घातांक और घात में से घन प्रतिगमन मॉडल क्षेत्र, उत्पादन और उपज श्रृंखला के लिए सभी मापदंडों (R^2, समायोजित R^2, RMSE और MAPE) में सबसे मजबूत और सबसे फिट था, खासकर जब तीन साल और पांच साल की चलती औसत का उपयोग करके इसे सुचारू किया गया। उल्लेखनीय रूप से, क्यूबिक मॉडल ने दलहन की खेती, विशेष रूप से चना, मसूर और उड़द की खेती के दीर्घकालिक रुझान की पहचान करने में उत्कृष्ट व्याख्यात्मक क्षमता और पूर्वानुमान सटीकता का प्रदर्शन किया। रिपोर्ट चना और मटर जैसी फसलों में गंभीर संरचनात्मक गिरावट की ओर इशारा करती है, जिसके लिए उन्नत बीज प्रौद्योगिकी, सुनिश्चित खरीद और इनपुट सब्सिडी जैसे उपायों की आवश्यकता है। हालाँकि मसूर और उड़द में हुई वृद्धि को बनाए रखने के लिए भी यह आवश्यक होगा, लेकिन बाद के दो फसलों में "खतरनाक" रुझान नहीं दिख रहे हैं। अध्ययन क्षेत्र में स्थायी दलहन की खेती के लिए नीति निर्माण, उपज पूर्वानुमान और रणनीतिक योजना के हित में कृषि समय-श्रृंखला आँकड़ों के मॉडलिंग के लिए उन्नत स्मूथिंग तकनीकों और उच्च-क्रम बहुपदों को लागू करने की आवश्यकता पर बल देता है।

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