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*Original Article*

# Changing Paradigms of Horticulture in Cold Deserts: A Decomposition and Regression Analysis of Apple Cultivation in Lahaul-Spiti(2010-2024)

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***Abstract -*** *This study analysed the growth trends and production patterns of the apple crop in the Lahaul-Spiti district of Himachal Pradesh over the period from 2010-11 to 2024-25. Using secondary data, the trends in Area, Production, and yield (productivity) were examined using Compound Growth Rate (CGR), instability index, decomposition analysis, and log-log regression analysis. The CGR was found high in Yield (40.76%), followed by Production (13.11%), and Area (2.09%), whereas low instability was found in Area, and high instability was found in Production and Yield. The decomposition analysis indicates that the yield effect emerges as the key driver of production growth, followed by the interaction effect and area effect, respectively. On the other hand, the log-log regression analysis result illustrates that the elasticity of output with respect to Area remains high and statistically significant, suggesting the strong elasticity of output to acreage expansion. This apparent contradiction can be explained by the biological lag of perennial crops such as apples. In the initial stages of these crops, it contributes minimally to output, which leads to slow growth. Nonetheless, as the tree achieves maturity, it accelerates yield as well as production growth. The study concludes that while the yield improvement has been the major contributor to the long-term production growth, the area expansion plays a crucial role in the short run. Therefore, the balanced approach should be the centre of focus, emphasizing the role of area expansion as well as yield improvement for the sustainable development of the apple sector in the Lahaul-Spiti district.*

***Keywords*** *- Apple Cultivation, Lahaul-Spiti, Decomposition Analysis, Regression.*

## 1. Introduction

Apple (Malus Domestica), known as the king of temperate fruits, serves as the linchpin of the global horticultural economy. It is widely cultivated in temperate climatic zones due to its high economic value, nutritional benefits, and strong market demand, as well as basic climatic conditions such as chilling hour requirements for proper flowering. As of 2025-26, the global apple market valuation is projected to reach approximately USD 108.42 billion, and by the end of 2030-31, to USD 130.95 billion, registering a CAGR of 3.85 per cent between 2026 and 2031 (Mordor Intelligence,2026; Business Research Company ). China is the dominant global player of apple production, with more than 50 per cent of the total global Production, followed by the European union, United States, India, Iran and Turkey(USDA,2026).

In India, apple cultivation is not just an agricultural activity but a requisite source for the socio-economic lifeline of the Himalayan states. The topography of the Himalayan states supports apple cultivation in India. The cultivation of apples in the Himalaya benefited not just the local livelihood but all those who are associated with apples, from cultivation to transportation and marketing. It is playing a crucial part in the income enhancement and employment generation through different stages, like orchard management, packaging, transportation and marketing. India ranked among the top producers of apples by volume in the world, yet the share of the global supply remains low. This is mainly due to a few reasons, such as good domestic demand and lower agricultural productivity as compared to other apple-producing countries. Turkey, Iran, Chile, Italy and New Zealand are the countries from which India primarily imports apples to meet the demand(PIB,2023). In India, Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Arunachal Pradesh are the major apple-producing regions. Among these regions, Himachal Pradesh is well known for its apple economy, which incorporates a major part in the local livelihood, and it is a significant element of the state's horticultural output.

The cultivation of apples in Himachal Pradesh has changed the entire agricultural landscape. The crop constitutes

a major share of the total Area under fruit crops and total fruit production in the state. As evident from the studies, apple cultivation occupies nearly half of the total Area under fruit crops and the majority of the total fruit production in the state, signifying its importance in the horticultural economy(Manoj and Vinod 2018). The apple industry not just brings livelihood opportunities to the cultivators but also employs a wide network of traders, transporters, and processing plants across the region. Traditionally, the apple cultivation primarily centered in the districts such as Shimla, Kangra, Kullu and Mandi, which offer favourable agro-climatic conditions for temperate fruit cultivation. Over Time, variables such as better varieties, government support, and technological development lead to the expansion of the Area under the apple orchards in different parts of the state. However, variables such as climatic unpredictability, technological advancement and changing cropping patterns have caused the dynamics of apple cultivation to change in recent times.

Recent studies have shown that the cultivation of apples in Himachal Pradesh is shifting towards higher altitude regions, as farmers pursue more favourable climatic conditions for apple cultivation(Kaur,2020). Factors such as climate change, rising temperature, and chilling hours requirements in traditionally apple-growing regions have forced farmers to move towards new apple varieties that require minimal chilling hours, explore new areas for apple orchards at higher elevations, and focus on diversification. Consequently, a higher altitude region like the Lahaul-Spiti district emerged as a viable location for the expansion of apple orchards.

The Lahaul Spiti district is a cold desert area distinguished by elevated altitude, minimal precipitation and harsh climatic conditions. Notwithstanding these severe climate conditions, the district has unique agro-climatic benefits that make it appropriate for the temperate fruit crops such as apple and apricot. In recent years, the farmers in the district have purposefully selected apple farming to diversify agricultural activities and to enhance their farm income. Horticultural programs by the government, expansion of road network, especially the Atal Tunnel, Rohtang and availability of better-quality planting materials have further motivated farmers to adopt apple farming in the region. Although apple cultivation in higher-elevation areas is hampered by several factors, such as productivity oscillations caused by pollination deficits (Fraser et al., 2024), weather volatility, unpredictable snowfall, frost damage, and other environmental factors affecting fruit development. Irregular rainfall, pest attack, and orchard management issues are the primary drivers of yield fluctuation that cause high instability in apple production (Anjali et al., 2025). A detailed time series analysis of apple cultivation in Lahaul-Spiti can give an understanding of the growth patterns, productivity trends, and instability associated with the apple in this high-altitude environment. The present study seeks to analyse the pattern of apple farming in Lahaul-Spiti from 2010-11 to 2023-24. Using time series data, the study examines the trends in Area, Production, and productivity to check the district's growth performance and variability of apple farming.

## 2. Literature Review

The horticultural land use pattern in Himachal Pradesh is witnessing changes both spatially and structurally, particularly regarding apple farming. Recent research reveals that the traditional belts of apple production are moving to the high-altitude areas. The increasing temperature, along with the variation in rainfall, has affected the traditional apple belts. According to Sahu et al. (2020), the reduction in winter chill hours in the mid-hill belt has resulted in the relocation of apple belts into the high-altitude areas.

Kaur (2020) also validated the spatiotemporal change, explaining that Shimla and Kullu have been the apple production hotspots, whereas Lahaul-Spiti and Kinnaur are emerging as new horizons owing to favourable agro-climatic factors. There is an inherent biological gestation lag between the transition from traditional farming to horticulture. Initially, after planting, the growth of the plantation is mainly horizontal, involving more area expansion (Devi & Prasher, 2019). According to Sharma and Singh (2021), the growth is vertical rather than horizontal as the orchards start to bear fruits at the commercial stage, where the yield effect dominates the area effect and as a consequence, production increases.

According to the findings of Rani et al. (2026), based on the decomposition model of Hazell, it was seen that the district had exhibited a very high CAGR, but the same was marked with high instability. The major cause of this instability was yield fluctuation, which invariably crossed 30% barrier in mid hill zone, as revealed by Anjali et al.(2025). In the case of Kumar and Parmar (2023), it was found that Apple makes up for 81.2 per cent of the total horticulture production, but it was observed that there was a wide disparity in the performance of various districts.

## 3. Research Gap

Existing studies focus on those regions of Himachal Pradesh that are traditionally rich in apple cultivation, leaving a void in the literature discussing the dynamics of apple cultivation in the emerging regions. Previously, several available studies focused on the traditional apple belts, which are already grown and have been under the policymakers' radar for apple production. Limited studies have been conducted on growth trends, instability analysis of Area, Production and yield of apple cultivation in the Lahaul-Spiti district, despite being one of the emerging regions for apple cultivation. By evaluating the study, it seeks to contribute to a better understanding of the development of apple farming in the district over Time to provide insight for policy intervention targeted at increasing Production and productivity in the Lahaul-Spiti district.

## 4. Objectives of the Study

1. To analyse the growth trends in the Area, Production, and yield of apples in Lahaul-Spiti from 2010 to 2024.
2. To measure the degree of instability in the Area, Production, and yield of apple cultivation in Lahaul-Spiti.
3. To analyse the effect of Area, yield, and their interaction on apple production using the decomposition analysis.
4. To examine the relationship between Area and apple production using regression analysis.

## 5. Materials and methods

The present study is based on secondary time-series data for the period 2010-11 to 2024-25 on apple cultivation in the Lahaul-Spiti district. Data on the Area (hectares)and Production (metric tonnes) of apples were collected from the official website of the Department of Horticulture, Government of Himachal Pradesh.

Yield (productivity) was computed as:

$$\text{Yield} = \frac{Production}{area}$$

### *5.1. Growth Trend Analysis*

The growth trends in Area, Production, and yield were estimated using the semi-log regression model (Gujrati 2003).

$$lnY_t = a + bt + e$$

Where:

- $Y_t$ = Area/Production/Yield in year'$t$'.
- $a$ = Intercept
- $b$ = Regression (growth) coefficient
- $t$ = Time (year)
- $e$ = Error term

The coefficient $b$ represents the instantaneous growth rate. The compound annual growth rate (CAGR) was calculated as:

$$\text{CAGR} = (e^b - 1) \times 100$$

### *5.2. Measurement of Instability*

Using the Cuddy-Della Valle instability index (Cuddy and Della Valle, 1978), the instability in Area, Production, and yield has been measured.

$$\text{CDVI} = CV \times \sqrt{1 - R^2}$$

Where:

- CV = Coefficient of variation
- $\bar{R}^2$= Adjusted coefficient of determination from the trend regression

### *5.3. Decomposition Analysis*

To measure the change in Production due to the interaction of Area and yield, the decomposition analysis has been used (Minhas & Vaidyanathan,1965).

$$\Delta P = Y_0 \Delta A + A_0 \Delta Y + \Delta A \Delta Y$$

- $\Delta P$ = change in Production
- $\Delta A$ = change in Area
- $\Delta Y$ = change in yield
- $A_0, Y_0$ = base period value, base year is selected as 2010-11
- Area effect = $Y_0 \Delta A$, change in Production due to a change in Area, taking the yield constant
- Yield effect = $A_0 \Delta Y$, Change in Production due to a change in yield, taking the area constant
- Interaction effect = $\Delta A \Delta Y$, the combined effect of Area and yield on Production

### *5.4. Regression Analysis*

A log-log regression model was used to analyse the relationship between the Area and the apple production, which captures the elasticity of Production with respect to Area (Gujarati, 2003):

$$\ln P = a + b \ln A$$

- where $P$ represents Production, and $A$ represents Area. The coefficient of $b$ is the elasticity, and $a$ is the intercept.
- If $b$=1, A 1 percent increase in apple growing Area leads to a 1 percent increase in apple production.
- If $b$> 1, A 1 percent increase in Area leads to more than a 1 percent increase in Production.
- If $b$< 1, A 1 percent increase in Area causes less than a 1 percent increase in Production.

## 6. Results and Discussion

**Table 1. Area, Production, and Productivity of Apple crop in Lahaul-Spiti District**

| Year | Area (Hectare) | Production (Metric Tonne) | Productivity (MT/Ha) |
|---|---|---|---|
| 2010-11 | 1320 | 194 | 0.14697 |
| 2011-12 | 1410 | 126 | 0.089362 |
| 2012-13 | 1473 | 169 | 0.114732 |
| 2013-14 | 1579 | 200 | 0.126662 |
| 2014-15 | 1653 | 277 | 0.167574 |
| 2015-16 | 1673 | 272 | 0.162582 |
| 2016-17 | 1682 | 305 | 0.181332 |
| 2017-18 | 1702 | 300 | 0.176263 |
| 2018-19 | 1746 | 302 | 0.172967 |
| 2019-20 | 1762 | 302 | 0.171396 |
| 2020-21 | 1776 | 310 | 0.17455 |
| 2021-22 | 1793 | 751 | 0.418851 |
| 2022-23 | 1797 | 518 | 0.288258 |
| 2023-24 | 1825 | 756 | 0.386301 |
| 2024-25 | 1856 | 1200 | 0.646552 |
| **CAGR** | **2.09** | **13.11** | **40.76** |

*Source: Directorate of Horticulture, Shimla, Himachal Pradesh*

Table 1 shows the annual data of Area, Production and productivity of apple cultivation in the Lahaul-Spiti district of Himachal Pradesh over the years of 15 years from 2010-11 to 2024-25.

**Table 2. Growth Trends of Area, Production and Yield of Apple**

| Variables | Coefficient (b) | t-value | p-value | $R^2$ | Adj. $R^2$ | CGR(%) |
|---|---|---|---|---|---|---|
| **Area** | 0.02069*** | 8.55 | 0.000 | 0.84 | 0.83 | 2.09 |
| **Production** | 0.12327*** | 7.94 | 0.000 | 0.82 | 0.81 | 13.11 |
| **Yield** | 0.10259*** | 6.30 | 0.000 | 0.75 | 0.73 | 40.76 |

*Source: Computed by the author based on the data from the Directorate of Horticulture, Shimla, Himachal Pradesh*
*Note: *** significant at 1% level, $p < 0.01$*

The apple cultivation in the Lahaul-Spiti district is showing an overall increasing trend in Area, Production, and yield from 2010-11 to 2024-25. From 1320 hectares in 2010-11 to 1856 hectares in 2024-25, the Area under apple cultivation in the district expanded with the CGR of 2.09 per cent per annum, with positive and statistically significant growth. The adjusted $R^2$ value is 0.83, indicating that 83 percent of the variation in Area is explained by Time.

Apple production grew at a higher growth rate of 13.11 per cent per annum, statistically significant at the 1% level. The Production rises from 126 MT in 2010-11 to 1200 MT in 2024-25, with a value of 0.81 of adjusted $R^2$. The yield of apples recorded a massive growth of 40.76 per cent per annum, highly statistically significant at the 1% level, with the 0.73 value of adjusted $R^2$.

Table 1 clearly indicates that the growth rate of the yield exceeds the growth rate of both Production and Area. The increase in Production is primarily driven by the increase in productivity rather than the increase in Area, as evident from the analysis.

**Table 3. Instability in Area, Production and Yield**

| Variable | Mean | SD | CV (%) | Adj.$R^2$ | CDVI (%) |
|---|---|---|---|---|---|
| **Area** | 1669.8 | 159.017 | 9.52 | 0.8686 | 3.4518 |
| **Production** | 395.4 | 287.669 | 72.754 | 0.6327 | 44.089 |
| **Yield** | 0.2282 | 0.14906 | 65.293 | 0.59 | 41.798 |

*Source: Computed by the author based on the data from the Directorate of Horticulture, Shimla, Himachal Pradesh*

Instability in Area, Production, and yield was measured using the Cuddy-Della Valle index, where a value between 0-15 is considered low instability, 15-30 is considered medium instability, and 30 and above is considered high instability. Table 3 shows the values of CDVI of Area, production, and yield, where the Area under the apple crops showed stability with the value of 3.45, whereas the Production and yield exhibited high instability with the values 44.08 and 41.79, respectively. There are many reasons for instability in Production and yield, such as unpredictable climate, pests and diseases.

Despite high growth in both Production and yield, instability was found to be high. The instability in Production and yield may be due to several factors, such as climatic unpredictability, lack of pollinator diversity, and the unavailability of the right information.

**Table 4. Decomposition of Change in Production**

| Component | Value | Percentage Contribution (%) |
|---|---|---|
| Area effect | 49.4468 | 7.67014 |
| Yield effect | 456.683 | 70.8402 |
| Interaction effect | 138.537 | 21.4897 |
| Total Change($\Delta P$) | 644.667 | 100 |

*Source: Computed by the author based on the data from the Directorate of Horticulture, Shimla, Himachal Pradesh*

Table 4 shows the decomposition analysis, which reveals that the yield effect contributed a massive 70.84 percent in apple production, making it a dominant factor. The rise in Production is not only the result of the expansion of the Area, but also the enhancement of productivity per hectare. The adoption of better technology, better nutrient management, and the adoption of appropriate varieties suitable for the higher elevation.

The interaction effect accounts for 21.4 percent of the total output. This component represents the combined influence of simultaneous change in both Area and yield on the total output. Whereas, the area effect contributes the least, 7.67 per cent, which means the change in total output of apples in the Lahaul-Spiti district is the least affected by the area expansion.

The relationship between the Area and Production of apples is analysed using the log-log regression model. From Table 5, the coefficient of ln(Area) is 4.8, indicating that a 1 percent increase in Area leads to a 4.8 percent increase in apple production, representing increasing returns. The adjusted $R^2$ is 0.61, indicating that 61 per cent of the variation in output is explained by the Area, with the remaining 39 per cent attributable to factors such as climate conditions and technological change.

**Table 5. Regression Analysis of the Relationship between Area and Production of Apples**

| Variable | Coefficient (*b*) | Std. error | t-stat | p-value |
|---|---|---|---|---|
| **Intercept** | -29.99*** | 7.4381 | -4.032 | 0.0014 |
| **ln (Area)** | 4.82*** | 1.0029 | 4.811 | 0.0003 |

*Source: Computed by the author based on the data from the Directorate of Horticulture, Shimla, Himachal Pradesh*
*Note: *** significant at 1% level, $p < 0.01$*

The estimated equation arises from the regression analysis between Production and the apple cultivation area. $\ln(\text{Production}) = -29.995 + 4.8256 \cdot \ln(\text{Area})$Figure 1 shows the logarithmic relationship between Area and Production of apples in the Lahaul-Spiti district. The slope coefficient is positive, with an upward-sloping trend line indicating a direct relationship between the Area and Production, with high and sensitive elasticity. Regression analysis explained that the apple production growth in Lahaul-Spiti is primarily driven by Area rather than yield.

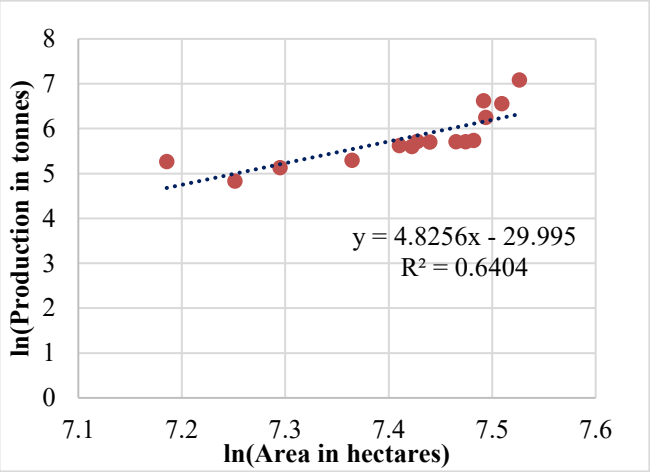


**Fig. 1 Logarithmic relationship between Area (ha) and Production (tonnes) of Apple in Lahaul-Spiti**

The empirical result reveals a dual characteristic in the cultivation of apples in Lahaul-Spiti. The result of the decomposition analysis reveals that 70.8 per cent of the production growth is due to the yield effect. In contrast, the regression analysis attributes the high elasticity of output with respect to Area, where a 1 per cent increase in Area leads to a 4.8 per cent increase in Production. In the case of perennial crops, this situation is normal due to the gestation period required for the apple tree, unlike annual crops (Peas, potatoes, etc.). It took 5-8 years for an apple tree to be able to bear fruit for commercial use. As a result, the expansion in cultivated Area does not immediately increase Production; instead, it will be reflected over Time as improvements in yield. This biological lag creates a scenario in which the impact of area expansion indirectly reflects in the yield effect and interaction effect in decomposition analysis.

## 7. Conclusion

The study analysed the growth trends, the degree of instability of the Area, Production, and yield of the apple crop over the period of 15 years (2010-11 to 2024-25). The district experiences positive growth in all three aspects, where the yield showed an impressive double-digit growth, followed by the Production and Area, respectively. In contrast, the CDVI result revealed that the high instability was found in Production and yield, whereas the Area showed low instability. After the decomposition analysis, the result clearly indicates the dominance of the yield effect, followed by the interaction effect and area effect, respectively. The dominance of the yield effect is a positive sign, as it is not possible to continuously increase the land area, especially in the case of Lahaul-Spiti, where cultivable land is already scarce. Since the CGR of Yield is very high compared to production and area growth, the focus of policymakers should be on how to sustain the growth of yield for the longer period and to prepare measures to minimise the instability in yield and Production by introducing climate-resilient farming practices, better and improved irrigation support, crop insurance schemes, etc. Further expansion of cultivated Area remains a key driver for apple production growth. The result also implies that the biological lag exists in perennial crops such as apple, where the gestation period delays the full realisation of Production from the area growth, observed from the production patterns. This highlights that while the area expansion drives Production in the short run, yield improvement is the key driver of growth in the long run. Policymakers need to focus on higher altitude regions such as Lahaul-Spiti for the expansion of apple production, as evident from the studies(Rana et al.,2011; Sahu et al.,2020), the apple belt is shifting towards the higher altitude regions, to achieve the full potential of the favourable climatic conditions available for apple cultivation.

## Limitations of the Study

The study is limited to apple cultivation in the Lahaul Spiti district; therefore, the findings may not apply to other regions due to the very limited availability of regions having similar agro-climatic conditions. The study is confined to the Area, Production, and yield, not covering other variables such as climatic variability, irrigation practices, and technical and marketing knowledge, which directly and indirectly affect apple cultivation. The study does not take into consideration the after-effects of apple cultivation on the socioeconomic conditions of the cultivators. Therefore, the study findings should be interpreted within these limitations.

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