Impact of Climate Change on Fruit Crops of District Solan, Himachal Pradesh, India

Report

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STATE CENTRE ON CLIMATE CHANGE

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EXECUTIVE SUMMERY

With noticeable changes in productivity, crop yield quality, and acreage already being observed globally, climate change has become a major problem for the horticulture sector. Seasonal trends in climatic variables such as minimum, maximum, and diurnal temperatures, as well as rainfall patterns (quantity and rainy days), were combined with a standardised anomaly index to determine the relationship between climate and crop production based on the phenological stages of pre-flowering, flowering, and fruit setting. To achieve these goals, 30 years (1990–2019) of horticulture data including production, acreage, and temperature of the Solan district were analysed by using statistical tools such as the Standardized Anomaly Index (SAI), the Menn Kendall Test, and Multivariate Linear Regression Analysis.

Thirteen fruit crops were assessed, viz., Apple, Plum, Peach, Apricot, Pear, Dry Fruits, Orange, Malta, Kagzi Lime, Galgal, Mango, Litchi, and Guava. Analysis of temperature and rainfall during the different phenological stages revealed that during the pre-flowering stage, no significant variations were seen. Whereas for flowering stages, the minimum temperature increased significantly by 0.151°C per year, whereas the diurnal temperature during these phenological stages showed a highly significant decrease of -0.158°C per year. Additionally, annual rainfall was significantly reduced, at -0.082 mm per year, during the flowering stage. However, at a rate of -0.031°C per year throughout the fruit setting stage, the average minimum temperature drastically dropped.

The results of the Mann-Kendall trend analysis showed that the production of the following fruits increased significantly: Plum, Peach, Apricot, Pear, Orange/Kinow, Kagzi Lime, Galgal, Mango, and Litchi. In contrast to the non-significant change for Apple and dry fruits, a considerable rise was seen for Malta and Guava. The biggest influence of climatic factors was reported for Malta and Guava, i.e., 44.4 percent and 42 percent, respectively, for the pre-flowering stage, according to a multivariate linear regression analysis of crop yields and climatic parameters. The influence of climatic factors on Malta during the flowering stage was the highest (59.9%), followed by Guava (57.9%), Orange (49.6%), and Apricot (30.9 percent). Mango had the greatest percentage impact (60%) on the fruit setting stage, followed by Guava (33%) and Kagzi Lime (3%). (29.5 percent).

With the increase in temperature and irregular rainfall patterns, the climate is undoubtedly changing, yet modest differences in the local environment may be advantageous or even favourable. According to the report's conclusions, most of the fruit crops in the Solan area have increased significantly, which is a good outcome.

CHAPTER 1 - INTRODUCTION

Climate change, described as climate fluctuations caused by direct or indirect anthropogenic behaviour in addition to natural climate variations that cause shifts in global atmospheric structure observed over comparable time periods, has seen manifestations in the horticulture sector across two parameters-erratic precipitation (rain and snowfall) and unknown temperature rises that has an unforeseeable effect on fruit crop productivity. Loss of vigour, fruit carrying ability, decreased fruit size and increased pest control inevitably result in low production and poor quality of temperate fruit crops such as apple, peach, plum and more. Various exploratory studies have explored the possible effect of climate variability on horticultural production, in the context of developing countries.

Horticulture is the primary agricultural sector, characterized by the size of growth and commercialisation, which plays a key role in promoting global food, economic and nutritional stability. Crop processing systems in South Asia and sub-Saharan Africa are observed at the receiving end of undisputed climatic exposure located at lower altitudes, these developing countries are still witnessing temperatures that are closer to or above the threshold, so any rise in mean temperatures is likely to negatively impact the productivity of horticulture crops (Malhotra, 2017). Samedi and Cochran (1976) illustrate the role of increasing temperatures in limiting vegetative growth and affecting the fruit environment of citrus fruits, which can be shown by burning or scorching flowers in higher plains, a phenomenon typically seen in desert areas. In the meantime, higher temperatures are also expected to modify precipitation patterns, leading to shifts in both frequency and intensity of droughts and floods. In South Asia, a median 11% shift in precipitation is expected by the end of the 21st century, with a decline in dry seasons and a rise during the year (IPCC, 2007).

India is the largest producer of Spices, Pulses, Milk, Tea, Cashew, Jute and the second largest producer of Wheat, Rice, fruit, vegetables, cane, cotton and oilseed. Moreover, India is the second largest producer of fruit and vegetables in the world and the largest producer of Mango and Bananas. Food grain production was expected to hit a record 29567 million tonnes during the 2019-20[1] crop year (IBEF, 2021). From 2005 to 2013, India released 20.54 billion tonnes of carbon dioxide equivalent (CO_2e), with emissions increasing by 5.57% annually. Emissions per capita have also risen by 4.07 % per year. In 2013, India released 2.8 gigatons of CO_2e – less than the US (6.2 gigatons of CO_2e) or China (11 gigatons CO_2e). Per capita emissions are

[1] as per 3rd advance estimate

still way below these countries (WRI, 2018). In India, mean temperatures are likely to rise by 3-4 °C by the end of 21st century, as per IPCC Fourth Assessment Report on Climate Change (IPCC, 2007). These exacting changes in temperature and precipitation patterns, irrespective of the study area, are expected to give rise to following omnipresent issues for the horticulture industry:

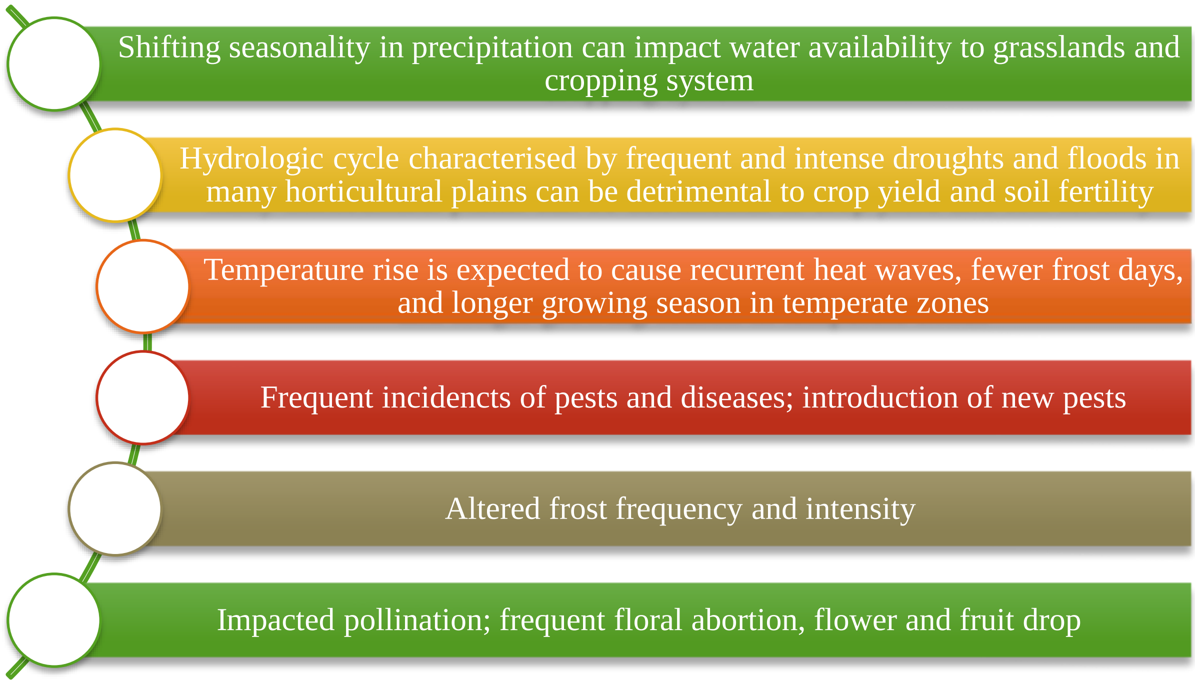

Figure 1 Horticulture and Climate Change Impact

Climatic conditions vary with fruit crop varieties and phenological phases of pre-flowering, flowering and fruit setting and development. Phenological phases have been established as the preferred and appropriate indicator for quantifying plant response to climate change (Chmielewski & Rötzer, 2001).

Table 1 The influence of precipitation and temperature variations on their effects during the three phenological stages: pre-flowering, flowering, and fruit setting stage.

Phenological Stage	Climate Change Impact
Pre-flowering	• Flower bud initiation is extremely sensitive to temperature variations from extreme high to low-growing season temperatures • High temperatures lead to under-development of plant reproductive organs
Flowering	• Soil moisture variations driven by changing temperatures also decide the flowering time and seed germination • Temperature rise leads to early bud sprouting (2-3 weeks in Apple and Almond) and increases susceptibility to frost damage (Choudhary et al., 2015) • Moderate winds during flowering stage enables better fruit setting; however harsh winds accompanied with heavy rains at low temperatures hinders appropriate flowering • Hailstorms anytime during the flowering stage are catastrophic for fruit crops
Fruit Setting	• Orchards deep seated in valley have better fruit setting as compared to plantations in windward sides

	• Spring frost can either destroy flower sexual organ or completely damage blossom with impacts on fruit-set • Frequent incidents of pests and diseases under high temperature conditions
Fruit Development	• Hailstorms anytime during fruit development stage are catastrophic for fruit crops • Excessive rains and fog near maturity leads to poor fruit quality with improper colour development and fungal spots • Extreme and sudden hailstorms lead to spotting and fruit drop, especially for temperate fruits. • High temperature decreases anthocyanin accumulation in fruit trees resulting fruit discoloration • High temperatures are known to alter fruit taste and flavour, sugar content, firmness, and antioxidant activity

The Himalayas and Climate Change Vulnerability

The Himalayas is one of the world's most vulnerable hotspots for global climate change, with especially rapid impacts. A crisis that is likely to deepen in the coming years, with dire and far-reaching impacts on food, water, and energy stability, as well as biodiversity and species extinction not only in the Himalayas, but across Asia. The Himalayan glaciers are the water reservoirs of Asia and the origins of three of the great rivers of the world: the Yangtze, the Ganges, the Indus, and the Mekong. Over a billion people are directly dependent on the Himalayas for their life, with more than 500 million people in South Asia, and another 450 million in China fully dependent on the health of this delicate mountain ecosystem (Malla, 2021). The Himalayan habitat is particularly vulnerable to the pressing threats of climate change. Although the focus of recent studies and discussions on glacial retreat and its effect on downstream water discharge has been increased, there is still increasing evidence of the possible cascading impact of climate change in the Himalayas on both related and satellite region. Due to its evolutionary past and structural rock structure, the vulnerable Himalayan ecosystem is quickly entering a state of imbalance, with apparent shifts in its wealth and climate.

The Indian Himalayan Region (IHR) is home to more than 72 million people living in more than 10 states, with 95 districts stretched over 5 square kilometres of lakes, accounting for about 16% of the country's geographical area. It offers an enabling ecosystem with optimal micro-climatic parameters for the cultivation of a wide range of horticultural crops such as Apples, Plums, Peaches, Bananas, Mangoes, Pineapples, Citrus Fruits, Nuts and more. Fruits and vegetables constitute about 16% of the total IHR agricultural land, with the western Himalayas accounting for about 20% of cropland and the central and eastern Himalayas responsible for about 5% of agricultural land. (Partap and Partap, 2010). However, due to its high biological and socio-cultural diversity, the Himalayan ecosystem is vulnerable to natural disasters that are likely to intensify the occurrence of floods, droughts and landslides caused by sudden changes in environmental conditions that would influence the lives and livelihoods of those who depend on the area for their economic and social needs.

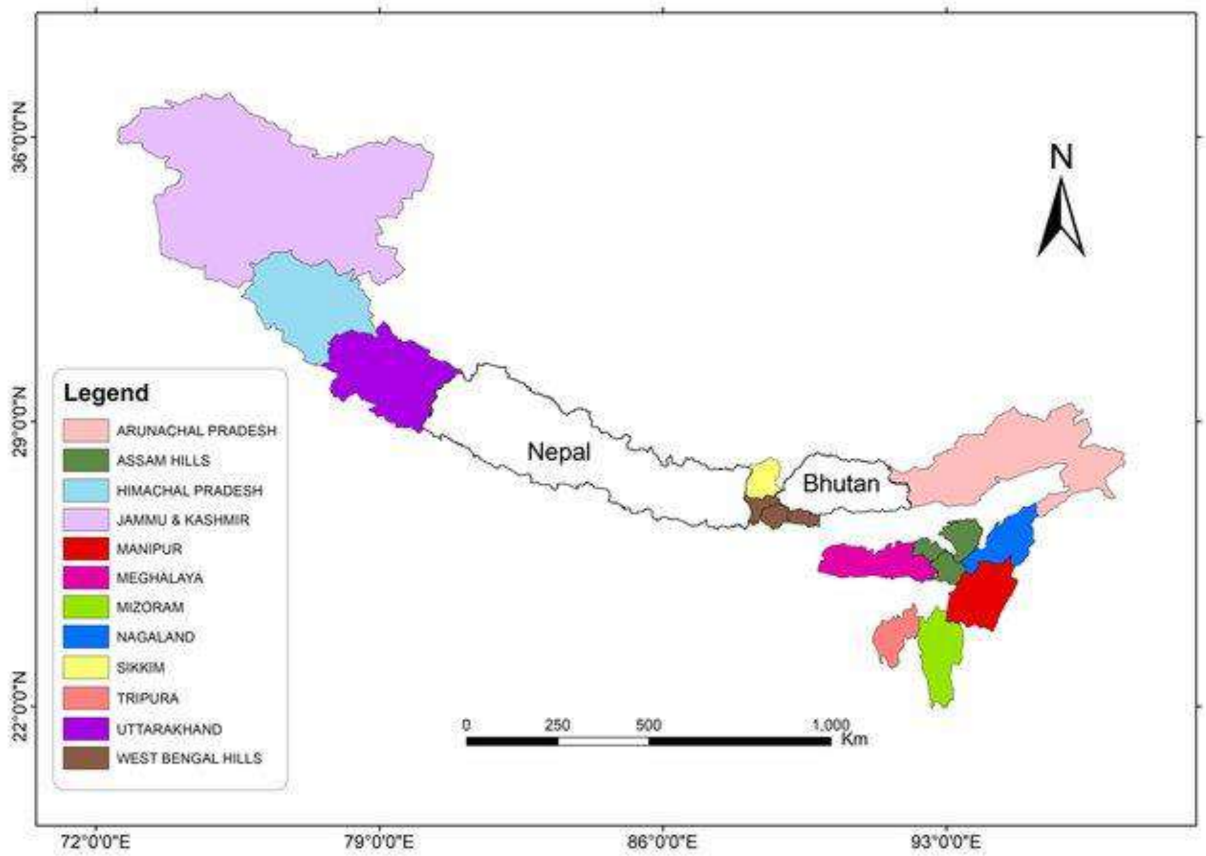

Figure 2: Geographical Representation of the Indian Himalayas

(Source: Siddique et al., 2019)

Striking vegetative shifts are observed in the western Himalayas, where different species of plants migrate to higher altitudes due to warming patterns (Padma, 2014), while others remain at risk of extinction. Additionally, the Hindu-Kush-Himalayan area is experiencing early greening patterns, though habitat losses of about 30 % are anticipated for Snow Leopards due to sustained forest losses (Panday & Ghimire, 2012 and Forrest et al., 2012). Furthermore, the delicate Himalayan area is also seeing a steady rise in temperatures above the world average of 0.7^{o}C in the last century. Rising demand from the burgeoning population, combined with global climate change, is moving the ecological hotspot to a precarious point of no return that could be unfavourable to the agricultural livelihoods of mountain populations.

Setting the Scene

Himachal Pradesh is a mountainous state in the northernmost region of India, located in the western Himalayas between 30º 22' 40" N to 33º 12' 40" N and 75º 45' 55" E to 79º 04' 20" E. The State has a complex topographic feature which dissects its topography in extreme altitudinal ranges from 350 m to 6975 m above sea level. According to these extreme differences in elevations, there are varying climatic patterns, ranging from hot and sub-humid tropical in the southern regions to icy, alpine, and glacial in the northern and eastern mountain ranges with higher elevations. There are 686 million residents in the province, almost 90 % of whom live in rural areas. Agriculture/horticulture continues to be a source of revenue and work for about 71% of the population and mixed farming, agro-pastoral, silvi-pastoral and agro-horticulture are the prevalent agricultural systems. Of the 5567 hectares of lakes, however, just 10% of the State's net area is under cultivated land and 81% of that cultivated area is rainfed. There is, however, just one lake hectare of net seed field with protected irrigation.

Himachal Pradesh is regarded as India's fruit bowl, with the horticulture industry contributing some 38% of state GDP from the primary sector (agriculture and related services contributed for 10% of state GDP in 2015-16); thus, providing a wide variety of farm and off-farm employment opportunities. (MoSPI, 2016).

Himachal Pradesh – Climatic Profile

The State has extensive exposure to climatic conditions for temperature and precipitation parameters. Depending on the altitude, the climatic conditions vary from hot and sub-humid tropical at 450m-900m in the southern lowlands, mild and temperate at 900m-1,800m, cold and temperate at 1,900m-2,400m, and cool alpine and glacial in the far northern and eastern mountain ranges at 2,400m-4,800m. The climatic profile of the state can be best understood with reference to its division into three physiographic regions – the outer Himalayas (covering the districts of Bilaspur, Hamirpur, Kangra, Una, and the lower parts of Mandi, Sirmour, Solan), the lower Himalayas (covering parts of the districts of Mandi, Sirmour, Chamba, Kangra, Shimla) and the Greater Himalayas or the Alpines (covering District Kinnaur, Lahaul & Spiti, Chamba).

Climate change has no consistent effect on any region, and with these topographical and varied climate classifications in Himachal Pradesh, susceptibility and risk quotients are becoming important and appear to differ from region to region. Substantial literature and studies are available to support the predicted varying effects of climate change in Himachal Pradesh. Based on the results of a short-term survey at various altitudes, Bhutiyani et al. (2007) found slightly higher temperature fluctuations in the north-west Himalayan region relative to the global average in the last century, and concluded that the rate of increase in maximum temperature increases is directly linked to the changes in altitudes. Kumar et al. (2009) and Shrestha et al. (2012) recorded an average rise of 1.52°C in annual minimum temperature (Kullu Valley, 1962-2004) and 1.5°C in annual mean temperature (25 years) in the state. About precipitation, Himachal Pradesh is experiencing a period of unpredictable and untimely rainfall and snowfall, which is likely to influence the supply of water and the maintenance of snow-fed gravity channels (*Kuhls*), thereby affecting irrigation support for agriculture and horticulture. According to the projections of the Himachal Pradesh State Action Plan on Climate Change (2012), a 40% drop in rainfall has been observed over the last 25 years. In brief, annual temperatures are forecast to increase for all seasons with major snowfall decreases in mid-hill temperate wet agro-ecological areas. Rainfall is forecast to rise but with decreased average severity, causing drought conditions in some pockets and accelerating summer flows in the north-western part of the state.

State's Agro-Ecological Profile

Himachal Pradesh has been divided into four agro-ecological zones based on characteristics of precipitations, altitude, cultivated and irrigated area. Table 2, below highlights the details for four zones with information on district coverage.

Table 2 Agro-Ecological (new) Classification, Himachal Pradesh

	Zone I	Zone II	Zone III	Zone IV
Ecology	Sub Montane & Low Hill Sub-tropical	Mid Hills Sub-humid	High Hills Temperate Wet	High Hill temperate dry
Geographic Area (%)	18.43	8.37	16.54	56.61
Cropped Area (%)	40	37	21	2
Irrigated Area (%)	17	18	8	5
Altitude (m)	240-1,000	1,001-1,500	1,501-3250	Above 2501
Mean Annual Temp	15 ºC - 23ºC	14 ºC - 22ºC	9.1 ºC – 20.6ºC	9 ºC - 20ºC
Rainfall (mm)	1,100	1,500 (except Dharmshala, Palampur: 3000mm)	1,000	>1,500
Soil	Shallow, Light textured, low fertility	Loamy to Clay loam deficient in Nitrogen and Phosphorus	Shallow, acidic, silt loam to loam, deficient in	Sandy loam, neutral to Alkaline, Low fertility

			Nitrogen and Phosphorus	
Major crops	Wheat, Maize, Paddy, Pulses, Oilseeds, Barley, Sugarcane, Potato Citrus fruits, Mango, Litchi	Wheat, Paddy, Barley, Pulses, Oilseeds Off-season vegetables Citrus Fruits	Wheat, Barley, Millets, Pseudo-Cereals (Buckwheat, Amaranthus), Maize, Potato, Oilseeds Off-season vegetables Apple and other temperate fruits and nuts	Wheat, Potato, Barley, Pseudo- Cereals (Buckwheat and Amaranthus), Peas, Minor Millets, Kuth and Temperate vegetables Apples, Grapes, Almonds, Walnuts, Apricot Zeera, Hops, Cumin, Saffron
Districts	Kangra, Una, Hamirpur, Bilaspur, Solan, and Parts of Chamba, Sirmaur	Parts of Chamba, Kangra, Mandi, Shimla, Sirmaur, Kullu, Kinnaur, Hamirpur, Bilaspur	Shimla, Chamba, Kangra, Mandi, Kullu, Solan, Sirmaur, Kinnaur, Lahaul & Spiti	Kangra, Lahaul & Spiti, Kinnaur, and Parts of Chamba, Mandi, Kullu, Sirmaur, Shimla

Source: Agro-Ecological Zonation of Himachal Pradesh – Agricultural System Information Development at micro-level, Centre of Geo-informatics, CSK Himachal Pradesh Agriculture University, Palampur

In Asia, human-managed habitats such as food production and livelihood sustenance have been discovered to be extremely vulnerable to climate change. While analysing five-year fruit production and meteorological data, Jindal et al. (2001) highlighted the instrumental role of abnormal climatic factors during the flowering and fruit growth stages in causing apple productivity reduction. Other factors, such as monoculture of delicious varieties, lowered orchard management standards, and others, were also found to be detrimental to fruit crop productivity, according to the report. Meanwhile, Crepinsek and Bogataj (2006) investigated the effect of rising temperatures (per degree) on the incidence of two-day ripening of leaves and fruits in apple and plum crops. Surprisingly, a few perception-based studies have concluded that climate change is altering the blossoming, bearing, and productivity of the apple crop. In the Kullu valley, Vedwan and Robert (2001) observed a notable change in the apple belt, as well as a major difference in the flowering periods of male and female trees. Nonetheless, a growing body of literature discusses historic and current weather parameters such as precipitation and temperature in relation to horticulture production, with little or no discussion of farmers' perceptions of their exposure, vulnerability, and adaptive ability to climate change as a result of observed changes in climatic parameters.

To close this gap, a status study was conducted in district Solan to evaluate the effect of climate change on the horticultural field. Seasonal trends in climatic variables such as minimum, maximum, and diurnal temperatures, as well as rainfall patterns, were combined with a standardised anomaly index and a multivariate regression analysis to determine the climate-crop yield relationship during the phenological stages of pre-flowering, flowering and fruit setting and growth.

Outline of Status Report

The status report designed to provide a snapshot view of statistical and perceived impact of climate change on horticulture in the state with an astute focus on District Solan and is organised as in Figure:

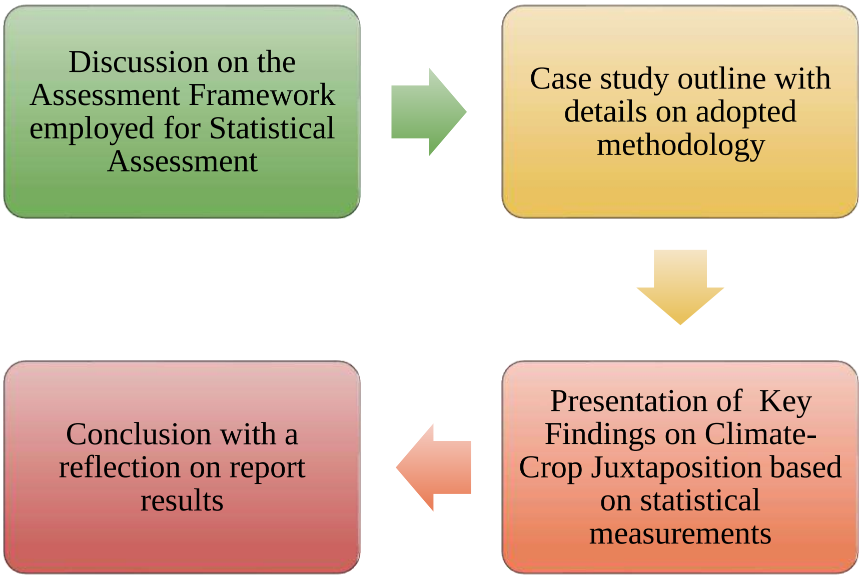

Figure 3. Showing different steps of the outline of Status Report

Climate of Solan

The district's climate is primarily subtropical in the lower regions and moist temperate in the upper reaches. Rainfall occurs during both the rainy and the winter seasons. At the higher elevations, snowfall occurs in the months of January and February. The temperature in the Satluj Basin is chilly in the winter and hot in the summer, with summers being moderately hot in the lower sections and cool in the top areas of the Solan and Lesser Himalayas. During the winter, the Bari Dhar range receives light snowfall. The climatic conditions in the Nalagarh Shiwalik region are like those in the surrounding Punjab and Haryana states.

The rainy season usually starts in the first week of July and lasts until the last week of August, but it can sometimes start a fortnight earlier and last until the end of September. The rainy season usually begins in the last week of December and lasts until the end of February. October, November, and May are the driest months of the year. During the months of January and February, snow is common in Chail, Kasauli, and Karol. The temperature in the district varies greatly due to considerable differences in height. During the winter, the minimum temperature drops below 0°C in higher elevations, while the maximum temperature rises above 40°C in lower elevations during the summer.

Horticulture

The state's diverse agro-climatic conditions are ideal for growing a wide variety of fruit crops. Horticulture in the state is playing a critical role in improving the socio-economic conditions of the rural population due to improved production and income per unit area from fruit crops. So far, the apple has been the state's most important fruit crop. Other fruit crops, such as citrus, mango, stone fruits, and others, are steadily emerging in promising locations. Because of the excellent agro-climatic conditions, the entire Solan district shows great promise for the cultivation of horticultural crops like stone fruits, citrus fruits, mushrooms, kiwi, beekeeping, floriculture in poly-green houses, and so on. The district's stone fruit orchards are mostly found in the tahsils of Solan, Kandaghat, and some areas of Kasauli. Citrus plantations are common in the lower reaches of the Nalagarh and Arki tahsils. Apart from stone and citrus fruits, apples are produced in the district's higher elevations, primarily in the Chail area of Kandaghat C.D. block. Dr. Y. S. Parmar, University of Horticulture and Forestry, is also a key player in the development of novel horticultural crop varieties.

CHAPTER 2 – STUDY AREA AND METHODOLOGY

Study Area-District Solan-A Background

Solan was established as an independent district on September 1, 1972, following the reorganisation of Himachal Pradesh's districts. The district takes its name from Solan, the area's administrative centre. The name Solan is supposed to be linked to Shoolini, the local deity. Solan, which is 48 kilometres from Shimla, is regarded the gateway to Himachal Pradesh's capital. The district was formed by combining the tahsils of Solan and Arki in the Mahasu district and the tahsils of Kandaghat and Nalagarh in the Shimla district. The district's geography is predominantly mountainous, with elevations ranging from 300 to 3000 metres above sea level. The number of tahsils/sub-tahsils grew from 7 to 9 between 2001 and Census 2011, with the creation of Darlaghat sub-tahsil and Baddi tahsil. In urban areas only Baddi promoted from Nagar Panchayat to Municipal Council with merging of 5 out growth villages and remaining towns have no change in civic status.

Methodology

The analysis employs three distinct statistical measures, namely a trend analysis based on the Mann-Kendall Test, the Standardized Anomaly Index, and the Multivariate Linear Regression Analysis, to determine the effect of climate parameter variations on horticulture in the pre-flowering, flowering, fruit environment, and development phonological stages. The mean minimum, maximum, diurnal temperatures, and rainfall records for Solan District were obtained from the India Meteorological Department (IMD), Shimla, and span the years 1990 to 2019. Datasets were further classified for different phenological stages, such as pre-flowering (February to Mid-March), flowering (Mid-March to April), and fruit setting stages (May to June). However, most of the region of the Solan district falls under the sub-tropical range, except for some peaks having temperate zones. The acreage and production data for the horticulture crops Apple, Plum, Peach, Apricot, Pear, Dry Fruits, Orange, Malta, Kagzi Lime, Galgal, Mango, Litchi, and Guava were collected by the Directorate of Horticulture, Himachal Pradesh from 1990 to 2019.

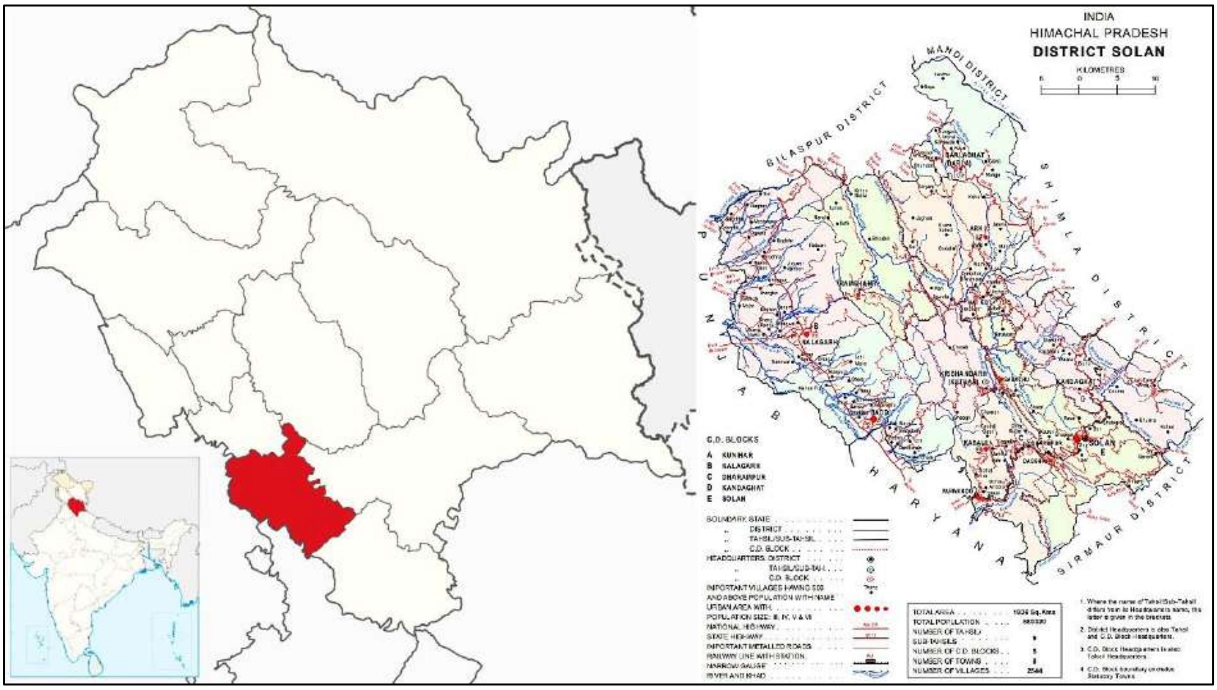

Figure 4 Administrative map of Solan, Himachal Pradesh, India

Mann Kendall Test

The Mann Kendall Test, a generally accepted statistical test for trend analysis in climatologic and hydrologic time series, was used to analyses seasonal patterns in climatic variables such as minimum, maximum, and diurnal temperatures, as well as rainfall (quantity and days) (Pohlert, 2018). This statistical test has two advantages: first, since it is a non-parametric test, it does not require normally distributed master data. Second, the test has a low sensitivity to abrupt data breaks and time series that are not homogeneous. Consequently, data gaps are filled by assigning a common value that is less than the master data set's smallest measure value. The Mann Kendall Test works on the basic null hypothesis H_o of no trend i.e., data is independent with a random order that is tested against the alternative hypothesis H_1.

The test follows a time series of *n* data points with *Ti* and *Tj* as two subsets of data where $i = 1,2, 3, n-1$ *and* $j = i+1, i+2, i+3, \ldots, n$.

Each data point in an ordered time series is compared to the next data point, and if the next data point has a higher value, the statistic S is incremented by 1, while if the next data point has a lower value, S is decremented by 1. The final value of S, i.e., the Mann Kendall S statistic, is calculated by the net results of all iterations.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\,(T_j - T_i)$$

$$Sign\,(T_j - T_i) = \begin{cases} 1\ if\ T_j - T_i > 0 \\ 0\ if\ T_j - T_i = 0 \\ -1\ if\ T_j - T_i < 0 \end{cases}$$

Where *Tj and Ti* are the annual values in years j and i, j > i, respectively. A positive (negative) value of *S* indicates an upward (downward) trend.

Sen's Slope, which basically computes the linear rate of change and intercept, measures the magnitude of the pattern. After evaluating a range of linear slopes, the Sen's Slope is determined as the median of all linear slopes, resulting in the magnitude of the observed seasonal pattern. The *p*-value is another statistic correlated with the Mann Kendall test. The greater the weight of evidence against the null hypothesis of no pattern, the lower the *p*-value (below 0.05). The statistical Mann Kendall test is performed on software XL-STAT, 2020 for this analysis. For the time span 1990-2019, the null hypothesis is checked at a 95% confidence level for minimum, maximum, and diurnal temperate, as well as rainfall (quantity and days). Annual productivity patterns for Apple, Plum, Peach, Apricot, Pear, Dry Fruits, Orange/Kinow, Malta, Kagzi Lime, Galgal, Mango, Litchi and Guava crops were also analysed.

Standardized Anomaly Index (SAI)

SAI is a widely used index for regional climate change studies that is determined by subtracting the long-term mean value of temperature and rainfall data sets from individual values and dividing by their standard deviation (Koudahe et al., 2017). In this way, for the study field, standardized temperature indices for mean minimum, maximum, and diurnal temperature of horticulture (for three phonological stages) were computed.

Multivariate Linear Regression Model

The linear multivariate regression statistical measure is chosen to assess the climate-crop yield relationship. A dependent variable is driven by multiple independent variables in a multivariate linear regression model and thus multiple coefficients are calculated. A careful selection of independent variables for which a correlation matrix is generated is correlated with a good outcome. Pearson's correlation coefficient was used to determine the strength of the relationship between climatic variables and crop productivity in this analysis. A correlation coefficient of -1 indicates a perfectly negative linear relationship between the two variables; a correlation of

0 indicates no linear relationship between the two variables (but probably a non-linear relationship); and a correlation coefficient of 1 indicates a perfectly positive linear relationship between the two variables. Correlation coefficient values can never be less than -1 or greater than 1.

The regression analysis verified the effect of anomalies in the studied climatic parameters on crop productivity, as demonstrated by the following linear model:

$$\Delta P = constant + (\alpha \ x \ \Delta T_{min}) + (\beta \ x \ \Delta T_{max}) + (\gamma \ x \ \Delta T_{dt}) + (\delta \ x \ \Delta R) + (\varepsilon \ x \ \Delta Rd)$$

Where, ΔP is the observed change in the productivity due to minimum, maximum, diurnal temperature, and rainfall in the respective phenological stages of the fruit crops. Coefficients α, β, γ and δ are the coefficients of minimum, maximum, diurnal temperature, and rainfall, respectively. ΔT_{min}, ΔT_{max}, T_{dt}, ΔR and Δ*Rd* are the observed changes in minimum, maximum, diurnal temperature, rainfall, and rainy days respectively for the cropping seasons during the study period.

CHAPTER 3 - CLIMATE TREND AND HORTICULTURE

Current Climate Trends- Solan

To study the impact of climate change in the Solan district of Himachal Pradesh, temperature (minimum, maximum, diurnal) and rainfall are used as explanatory indicators to capture the crux of climatic changes in the district. A highly significant shift in climatic factors was noticed during the pre-flowering season, flowering season, and fruit setting season, according to the statistical analysis, Mann-Kendall trend test. The Mann-Kendall test findings for minimum, maximum, diurnal temperature, and rainfall for the years 1990–2019 at a 95% confidence level are shown in Table 4. The overall trend of the above-mentioned climatic variables is shown in Figure 5 below. This graph represents the general picture of climatic variables for the Solan district, showing how temperature and rainfall vary during the phenological stages over the last 30 years.

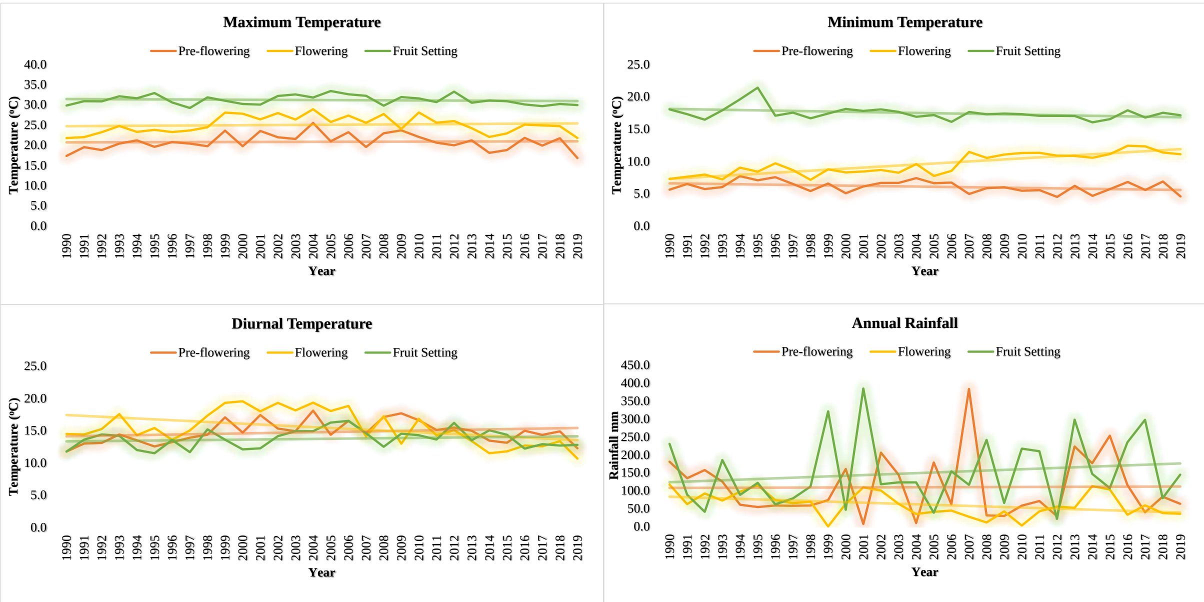

Figure 5 Variations in Climatic Parameters for Temperate region- Minimum T, Maximum T, Diurnal T and Rainfall during pre-flowering, flowering, and fruit setting stages (1990-2019), District Solan, HP

Analysis of climatic parameters, such as minimum, maximum, diurnal temperature, and rainfall, revealed that the average maximum and diurnal temperature increased at rates of 0.001^{o}C and 0.036^{o}C per year, respectively, during the pre-flowering stage. whereas the average minimum temperature and annual rainfall decrease at the rate of -0.044^{o}C and -0.033mm per year, respectively. The *p* value for all the above variables was >0.005, hence none of them showed a significant result. Maximum temperature increased at a rate of 0.007^{o}C per year with a *p* value of 0.925 during the flowering stages, while minimum temperature increased at a highly significant rate of 0.151°C per year with a *p* value of 0.001. In Kullu district, the yearly average minimum temperature for zone 2 increases by 0.89°C each decade, and the average minimum temperature in February and March rises by approximately 1.12°C and 0.97°C, respectively, per decade (Kapoor and Shaban, 2014). The diurnal temperature during these phenological stages showed a highly significant decrease of -0.158°C per year with a *p* value of 0.005 as shown in Table 4. The annual rainfall during the flowering stage was decreased significantly at-0.082 mm per year, which has a *p* value of 0.034 (significant). Similar observations were seen for the Sirmour district, where total rainfall in the period of 1991–2000 decreased over the years by 25.87 mm in spring and 86.90 mm in summer, while it increased in winter by 21.90 mm and 23.86 mm in autumn over the baseline period (Joshi and Verma, 2020).

Table 3. Illustrates the trend variation in climatic parameter during the three phenological stages i.e., pre-flowering, flowering, and fruit setting stages fruit crops of Solan district of HP

	Mean	Sen's slope	*p*- value
Pre-Flowering (February to Mid-March)			
Average Maximum Temperature	20.945	0.001	0.985
Average Minimum Temperature	6.089	-0.044	0.081
Diurnal Temperature	14.856	0.036	0.302
Annual Rainfall	8.741	-0.033	0.666
Flowering (Mid-March to April)			
Average Maximum Temperature	25.153	0.007	0.925
Average Minimum Temperature	9.653	**0.151**	**0.001**
Diurnal Temperature	15.499	**-0.158**	**0.005**
Annual Rainfall	2.792	-0.082	**0.034**
Fruit- Setting (May to June)			
Average Maximum Temperature	31.226	-0.040	0.171
Average Minimum Temperature	17.436	**-0.031**	**0.049**
Diurnal Temperature	13.790	0.013	0.666
Annual Rainfall	5.231	0.154	0.056

Values with Green color is highly significant and with red color is significant

Similarly, for fruit setting stages, these climatic variables showed varied results according to the analysis done. The average maximum and minimum temperature decreased at the rate of -0.040°C and -0.031°C per year, with a *p* value of 0.171 and 0.049 (significant) respectively. Meanwhile, the diurnal temperature and annual rainfall decreased at the rate of 0.013°C and

0.154 mm with a *p* value of 0.666 and 0.056 respectively. During the fruit setting stage, none of the climatic variables showed a significant change.

For the trend analysis of temperature parameters (maximum, minimum, and diurnal temperature), the Standardized Anomaly Index (SAI) was calculated for each phenological stage like pre-flowering, flowering, and fruit setting stages. In this analysis, 30 years of temperature trends are shown in the graphs, which show the temperature up and down. Analysis revealed that during the pre-flowering stage, SAI did not show any visual changes (Figure 6a). There was a greater temperature drop below the long-term average. During the flowering stages, the trendline lies parallel to the long-term average. Alongside, there were more cooling years as compared to warming years. Cooling years were observed from 1990 to 1998, 2007, 2009, and 2011, and a continuous drop in maximum temperature was seen from 2013 to 2019 (Figure 6b). Meanwhile, during the fruit setting stage, the SAI shows decreasing trends over the long-term average. Initially, from 1990 to 1992, there was a temperature drop, but for the next three years it consistently increased. From 1996 to 2001, the warming year was observed only for 1998. However, from 2002 to 2007, all warming years showed a temperature rise above the long-term average. After 2007, a temperature drop was observed from 2008 to 2019, except in 2009, 2010 and 2012 (Figure 6c). In other words, the maximum temperature of the Solan district didn't show any remarkable impact on the fruit's phenological stages.

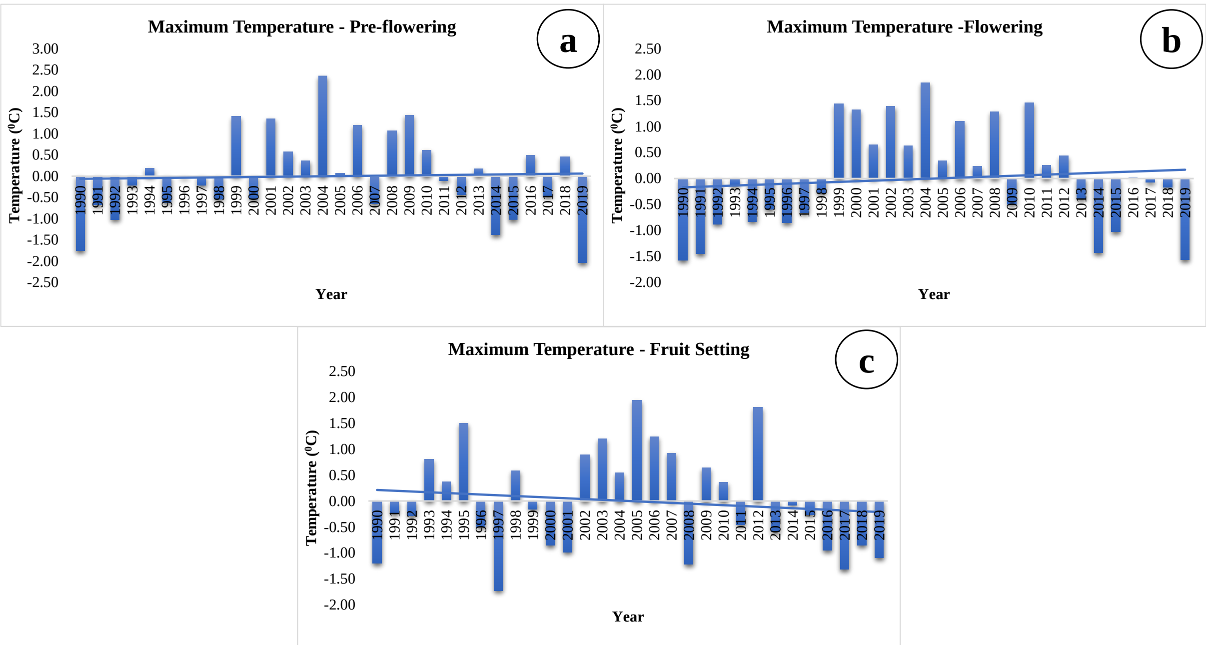

Figure 6. SAI (Standardized Anomaly Index) for Mean Maximum Temperature during pre-flowering, flowering, and fruit setting stages (1990-2019), District Solan, HP

Another temperature variable taken for the SAI analysis was the minimum temperature. During the pre-flowering stage, the minimum temperature showed a decreasing trend. More warming years were observed from 1990 to 2006, with a few drops in 1990, 1992, 1993, 1998 and 2000. After 2006, most of the years were cooling years, except 2013, 2016, and 2018 (Figure 7a). In contrast, during the flowering stages, a sharp and visual increasing trend was observed above the long-term average. A cooling trend was observed from 1990 to 2006, with a point increase in temperature for the year 1996. Subsequently, from the year 2007 to 2019, all show warming years (Figure 7b). In the fruit setting stage, the trendline shows a decreasing trend below the long-term average. The warming years (1990, 1993, 1994, 1995, 1997, 2000, 2001, 2002, and 2003) from 1990 to 2003 were more than the cooling years (1991, 1992, 1996, and 1998). From 2004 to 2019, the SAI shows more cooling years as compared to warming years, i.e., 2007, 2016, and 2018 (Figure 7c). In a nutshell, the mean minimum temperature shows a decreasing trend for pre-flowering and fruit setting stages while, increasing trend for flowering stages.

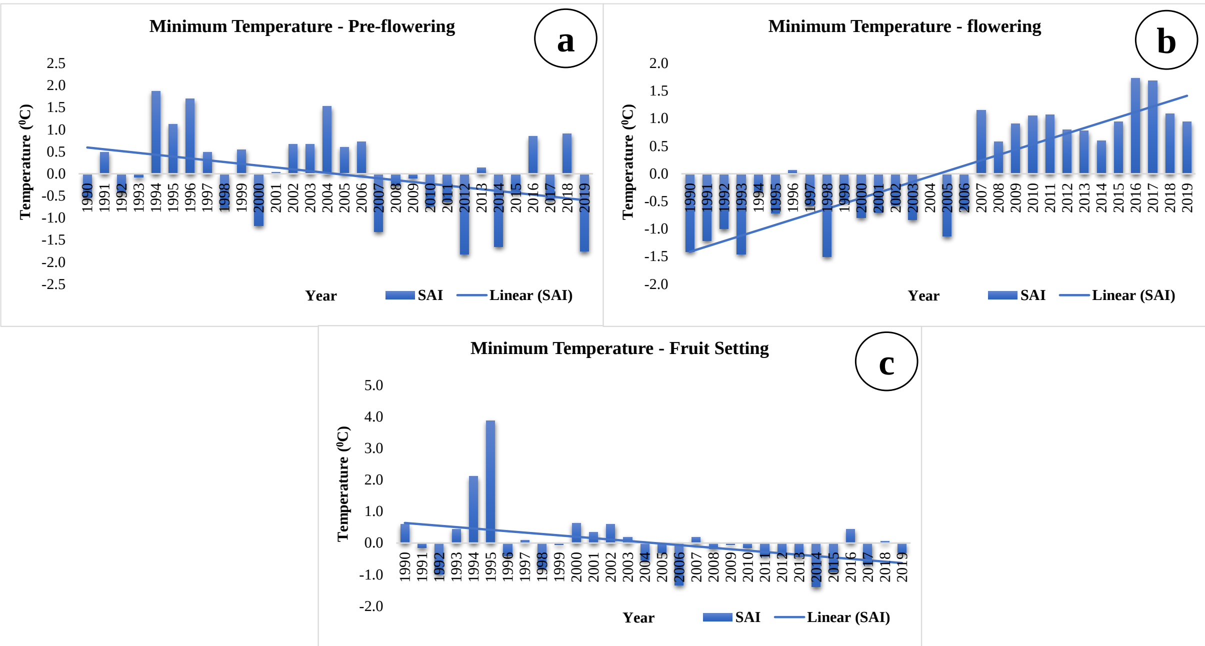

Figure 7 SAI (standardized Anomaly Index) for Mean Minimum Temperature during pre-flowering, flowering, and fruit setting stages (1990-2019), District Solan, HP

One more important temperature parameter is diurnal temperature, which is an important meteorological indicator connected with global climate change. SAI analysis revealed that during the pre-flowering stage, the diurnal temperature shows an increasing trend over 30 years. The initial nine years, i.e., 1990 to 1998, represent cooling years below the long-term average. From 1999 to 2019, more warming years were observed than cooling years above the long-term average. The warming years that were after 1999 were 2001, 2002, 2003, 2004, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2016 and 2018. However, the cooling years for this period are 2000, 2005, 2007, 2014, 2015, 2017 and 2019 (Figure 8a). In contrast, for the flowering stage, the diurnal temperature showed a decreasing trend. Early years from 1990 to 1997 exhibited more cooling years, except in 1993. From 1998 to 2006, all represented warming years, but after this a continuous cooling trend was observed except in 2008 and 2010 (Figure 8b). The diurnal temperature during the fruit setting stage showed an increasing trend with an intermittent variation in warming and cooling years (Figure 8c). The number of cooling years from 1990 to 2001 was higher, excluding 1992, 1993, and 1998. After 2001, the warming years were more till 2019, except for a few years having temperature drops for the years 2008, 2011, 2013, 2016, 2017, 2018 and 2019. In nutshell, the diurnal temperature showed an increasing trend for the pre-flowering and fruit setting stages, while for the flowering stage a decreasing trend was observed.

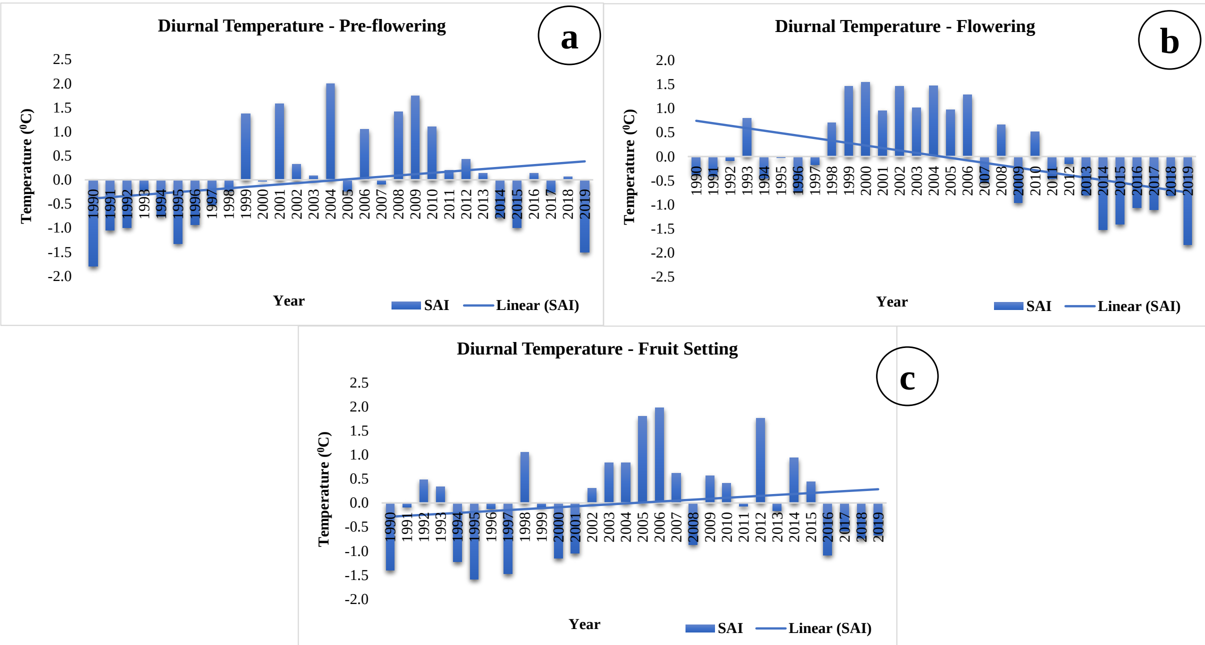

Figure 8 SAI (Standardized Anomaly Index) for Mean Diurnal Temperature during pre-flowering, flowering, and fruit setting stages (1990-2019), District Solan, HP

The fourth climatic variable was annual rainfall. The rainfall data from 1990 to 2019 was also analysed and the following trend was obtained. At the pre-flowering stage, the annual rainfall showed an interesting observation. The variation in warming and cooling years along the long-term average was so small that the trendline barely revealed a point change in the trend (Figure 9a). Meanwhile, for the flowering stage, a decreasing trend was observed, i.e., from 1990 to 2002, the temperature drop was observed for all years till 2019, except for 2009, 2013, 2014, and 2015 (Figure 9b). In contrast to the fruit setting stage, an increasing trend was observed

(Figure 9c). The yearly variation in annual rainfall showed intermittent observations, where the initial years showed more cooling years while the latter had more warming years. In general, the annual rainfall shows a marginal variation in the trend analysis.

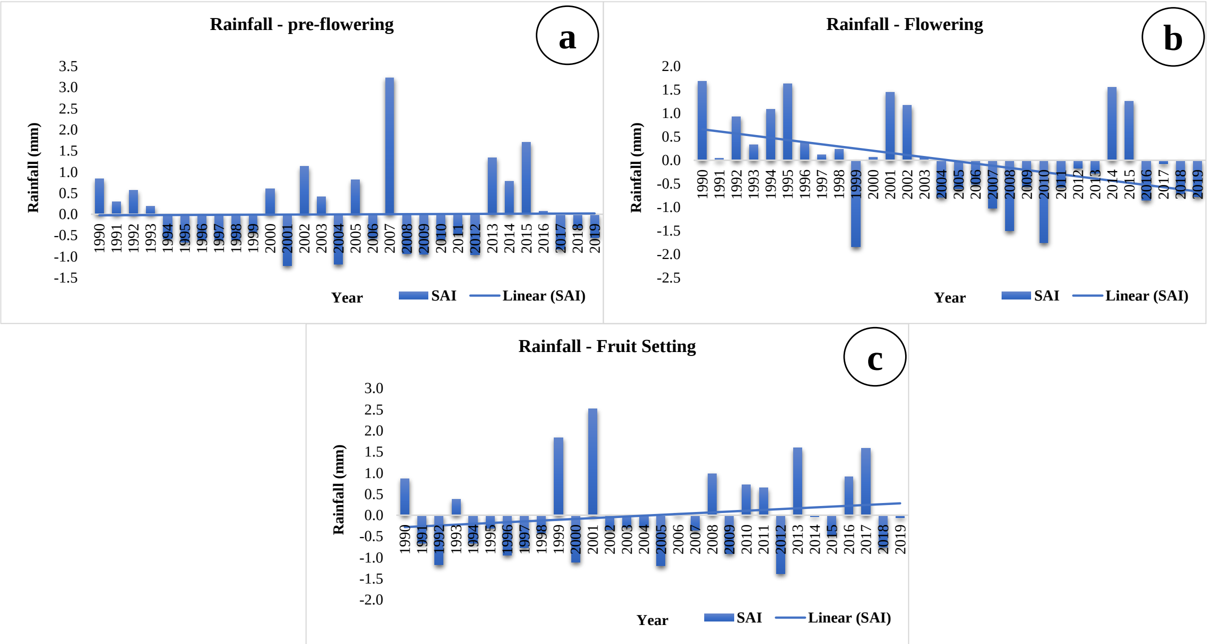

Figure 9 SAI (Standardized Anomaly Index) for Annual Rainfall during pre-flowering, flowering, and fruit setting stages (1990-2019), District Solan, HP

CHAPTER 4- FRUIT CROP PRODUCTIVITY

Acreage, Production, Productivity Assessment of Major Horticulture Crops

Temporal analysis for the acreage, production, and productivity was done for the Solan district to study the trends. The trends are presented graphically to show how areas, production, and productivity have changed over a period from 1990 to 2019. The detailed description of the figures is explained below:

Apple is the important fruit crop of the Solan district and is cultivated in the upper reaches of the district. Since the area under this crop is very small because of the geographic and climatic conditions. Analysis showed that there is a decreasing trend in the acreage of the Apple. The acreage was 528 ha in 1990, which showed an abrupt increase in the year 1992, which might be due to a data error because the increase was seen for this year only for the long-term data. After this year, the acreage remains at 529 ha with slight variation till 2001, then it decreases to 110 ha and continuously decreases, which leaves only 60 ha in year 2019 (Figure 10a). A similar trend was observed for the production. The production of Apple, which was 70 t in 1990, showed a slight increase in recent years but consistently decreased to 18 t in 2019. The productivity of the Apple crop in the Solan district showed an increasing trend. It was 0.13 t/ha in 1990 and in 2019 it was 0.30 t/ha, which is an increase of two times in the 30 years of history. However, the lowest productivity was recorded for 1992 and the highest for 2002, as shown in Figure 10b.

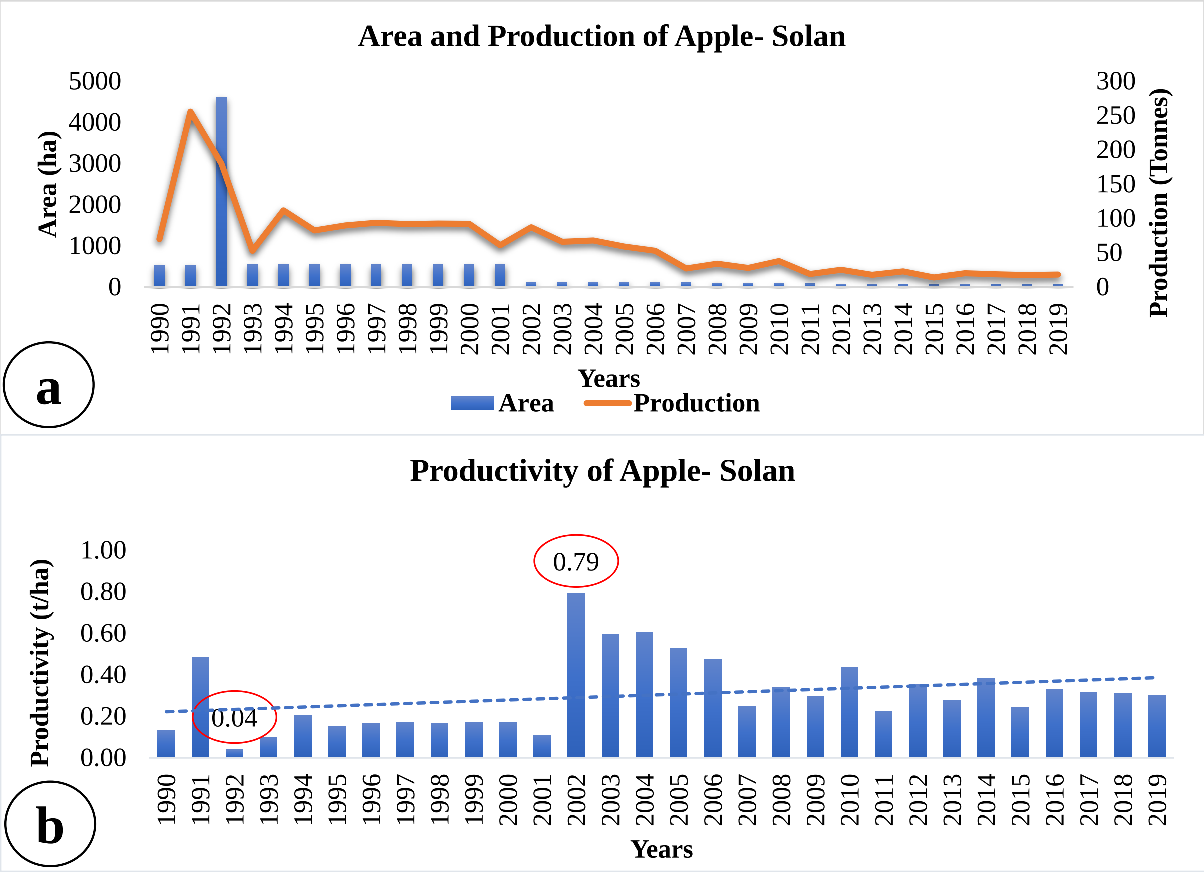

Figure 10 a&b. Variations in average acreage, production and productivity for Apple, district Solan, HP, (1990-2019)

Plum is the second important fruit crop of the district. The analysis revealed that a decreasing trend was observed for the acreage of the crop. Acreage from year 1990, to 2001 a uniformity was observed in the data but after that it decreases to 617 ha which is showing an abrupt drop (Figure 11a). After this decrease, with slight variations, it remained 645 ha in 2019. In contrast, the opposite observation was seen for the Plum crop in the district. The production was increased from 853 t/ha to 1420 t/ha despite the decrease in the acreage as shown in Figure 11b below. The productivity of Plum showed a decreasing trend from the year 1990 to 2019, wherein the maximum productivity was seen in the year 1992, i.e., 196.71 t/ha, and the lowest (0.22 t/ha) in 1994 (Figure 11b).

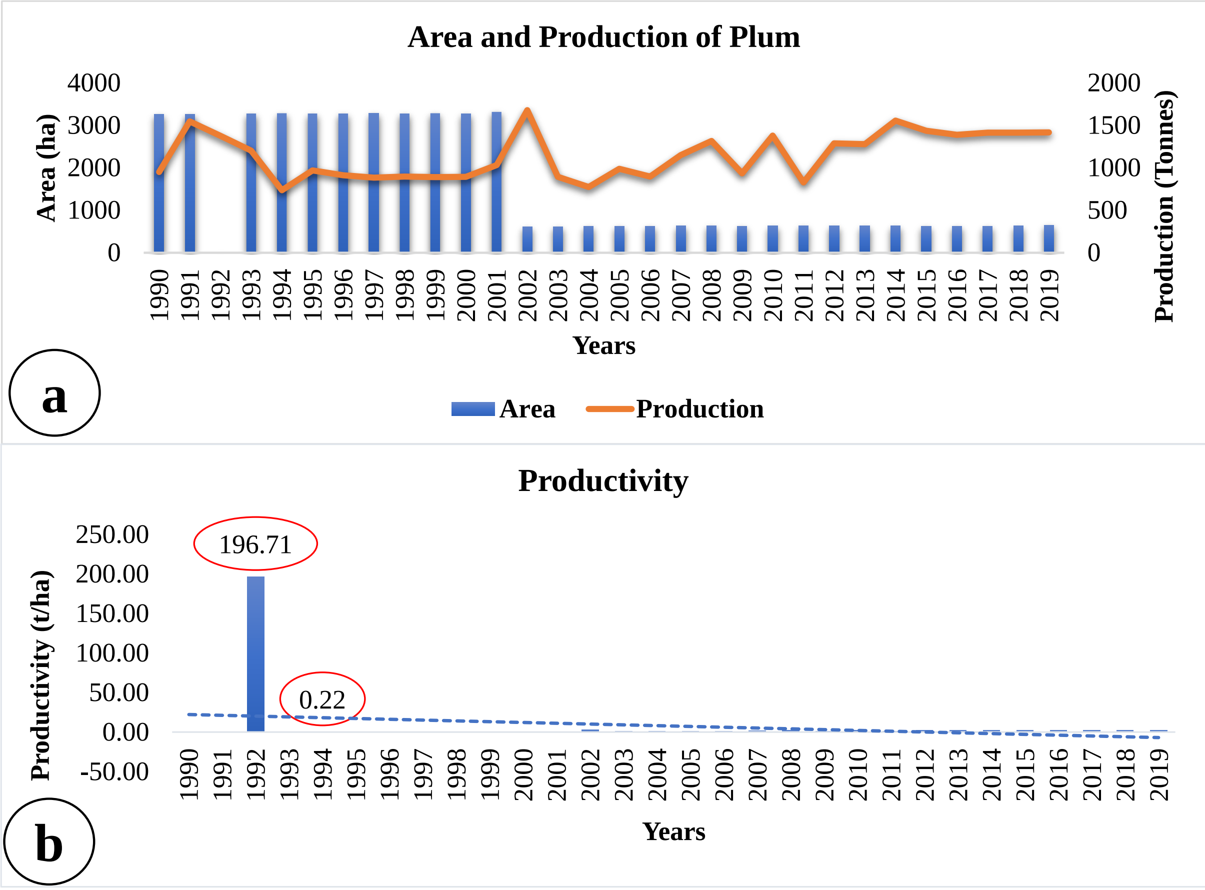

Figure 11 a&b. Variations in average acreage, production and productivity for Plum, district Solan, HP, (1990-2019)

The next crop is Peach. As per the data records findings, the acreage of the crop was decreased from 296 ha to 244 ha in the years 1990 to 2019 respectively. Apart from minor variations in the acreage, a sudden drop was seen for the year 1992. Likewise, the production of the crop has also increased in the district in the last 30 years. From 1990 to 2000, there were no such visual changes in the production, but after that a sharp increase was seen in 2001, which gradually decreased till 2009, and then, with an inconsequential increase, it was stable at 171 t in 2019. But in comparison to the initial year, the production has increased (Figure 12a). The productivity of the Peach showed an increasing trend for the Solan district. As the productivity of Peach increases from 0.02 t/ha (which is the recorded lowest for the district) to 0.70 t/ha in the years 1990 to 2019 respectively, as shown in Figure 12b. whereas the highest productivity was recorded for the year 2002, which was 1.22 t/ha.

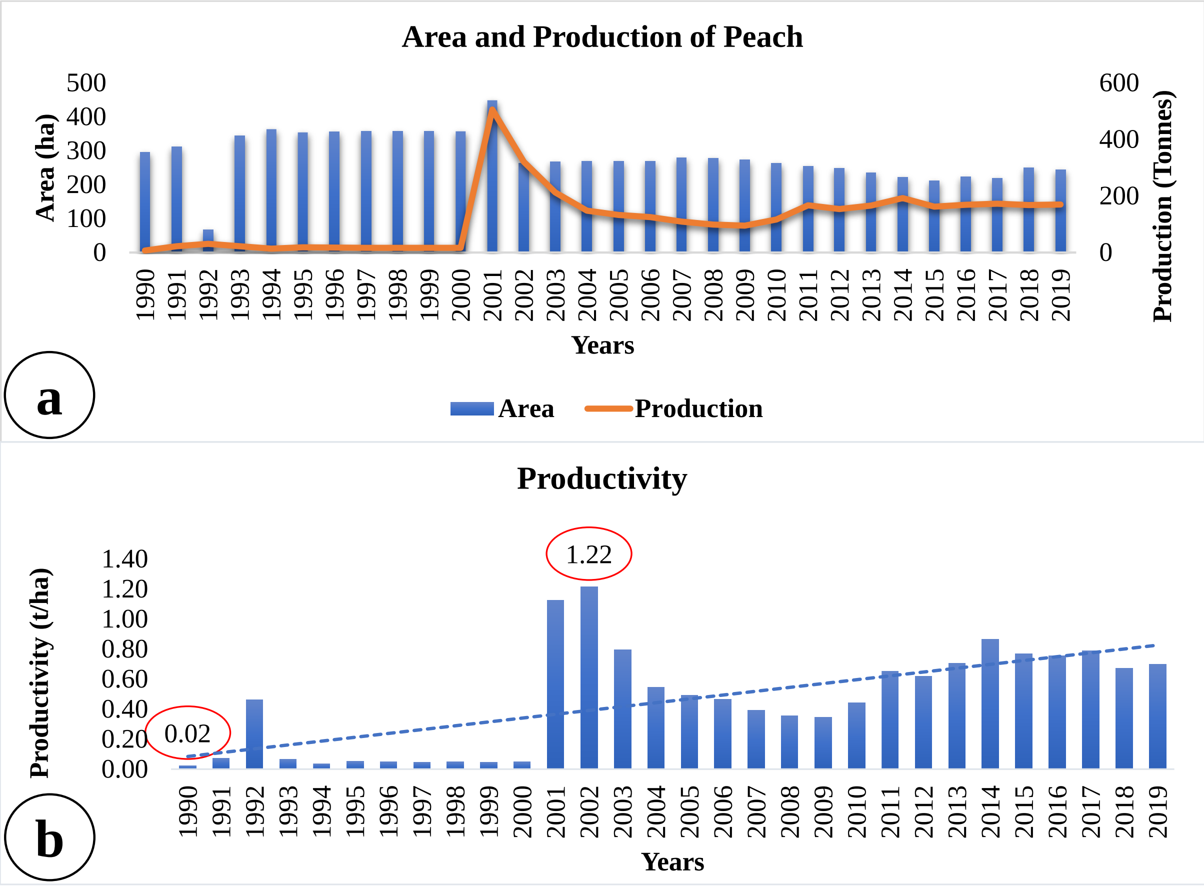

Figure 12 a&b. Variations in average acreage, production and productivity for Peach, district Solan, HP, (1990-2019)

The acreage of the Apricot in the Solan district showed an interesting trend where the acreage of the crop had been increased gradually from the year 1990 to 2019. In 1990, the acreage was 615 ha, which continuously increased till 2001 to 957 ha, and then, after a slight dip in 2002, it progressively increased and was stable at 1060 ha in 2019. In comparison to 1990, the acreage has doubled in the year 2019 (Figure 13a). Similarly, the production of the Apricot has been increased significantly in the last 30 years, i.e., from 1990 to 2019. The production of this crop was 614 t in 1990, which dropped next year to 57 t, and after small ups and downs, it maintained its stability at 126 t in 2000. After the year 2000, it started increasing continuously, which means it has approximately doubled as compared to the previous years. The highest production was observed for the year 2014, i.e., 2211 t and it remains at 1951 t in 2019. Similarly, Apricot productivity increased dramatically over the Solan district's 30-year history. The initial eight years from 1993 to 2000 did not show much variation in productivity (Figure 13b). However, there were dips in the productivity. Like, the lowest productivity of Apricot was observed for the year 1991, which was 0.09 t/ha, whereas the highest productivity was found for the year 2014, i.e., 2.10 t/ha.

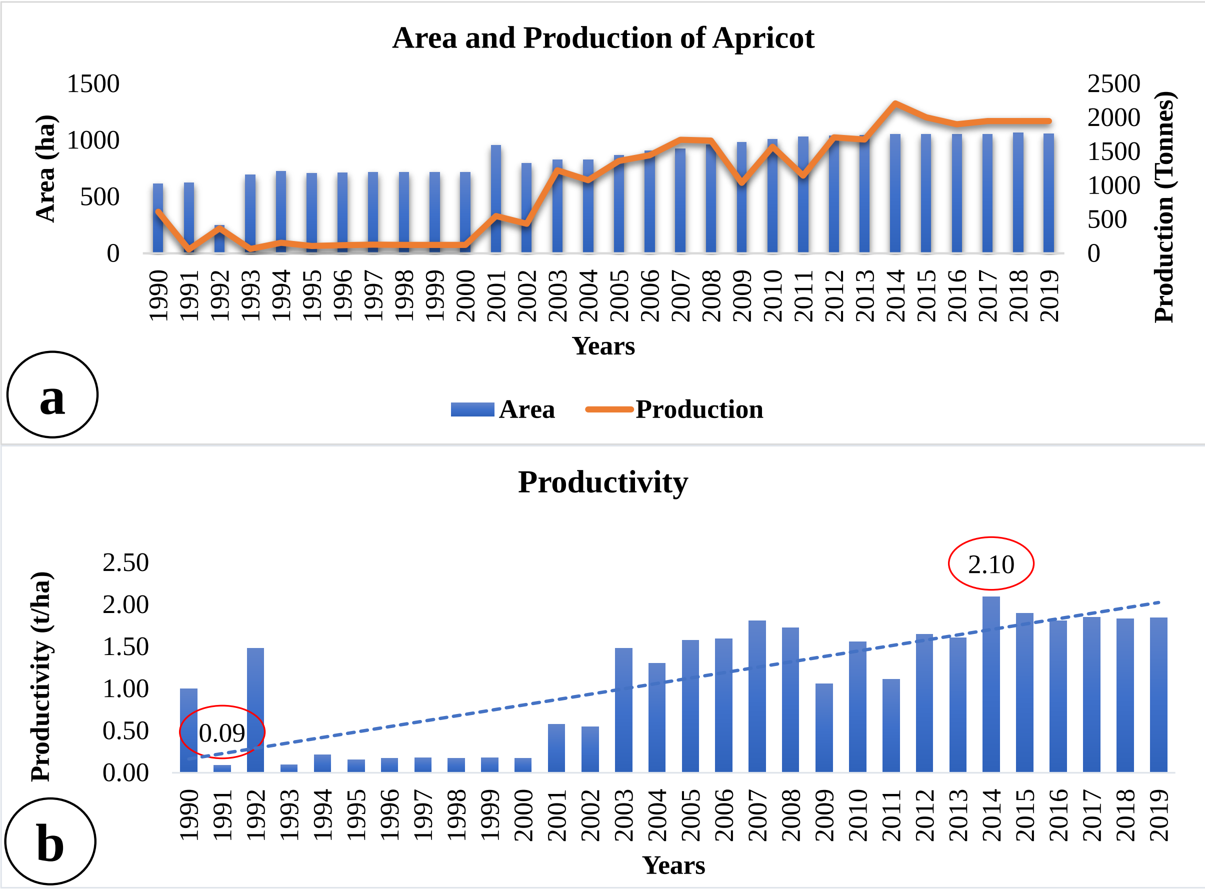

Figure 13 a&b. Variations in average acreage, production and productivity for Apricot, district Solan, HP, (1990-2019)

Analysis of the Pear for the Solan district revealed a wave like trend. From 1990 to 2000, the acreage increased, and the middle years of the long term showed the increase to the maximum and then again started to decrease steadily till 2019. However, the lowest acreage under this crop was recorded for the year 1992 (Figure 14a). After a slight variation in the beginning years, the production didn't show much change till 2003, but in 2004 it increased to the maximum in the last 30 years. After this, it again started to decrease till 2007; since then, with a continuous increase, it remains at 1545 t. In a nutshell, the acreage and production of the Pear were increased. In comparison, the productivity of Pear showed a decreasing trend from 1990 to 2019. However, the maximum productivity was seen for the year 1992, i.e., 121.77 t/ha (which is obvious when there is more production in less area, it will contribute to high productivity) and the lowest for the year 1993, i.e., 0.18 t/ha as shown in Figure 14b.

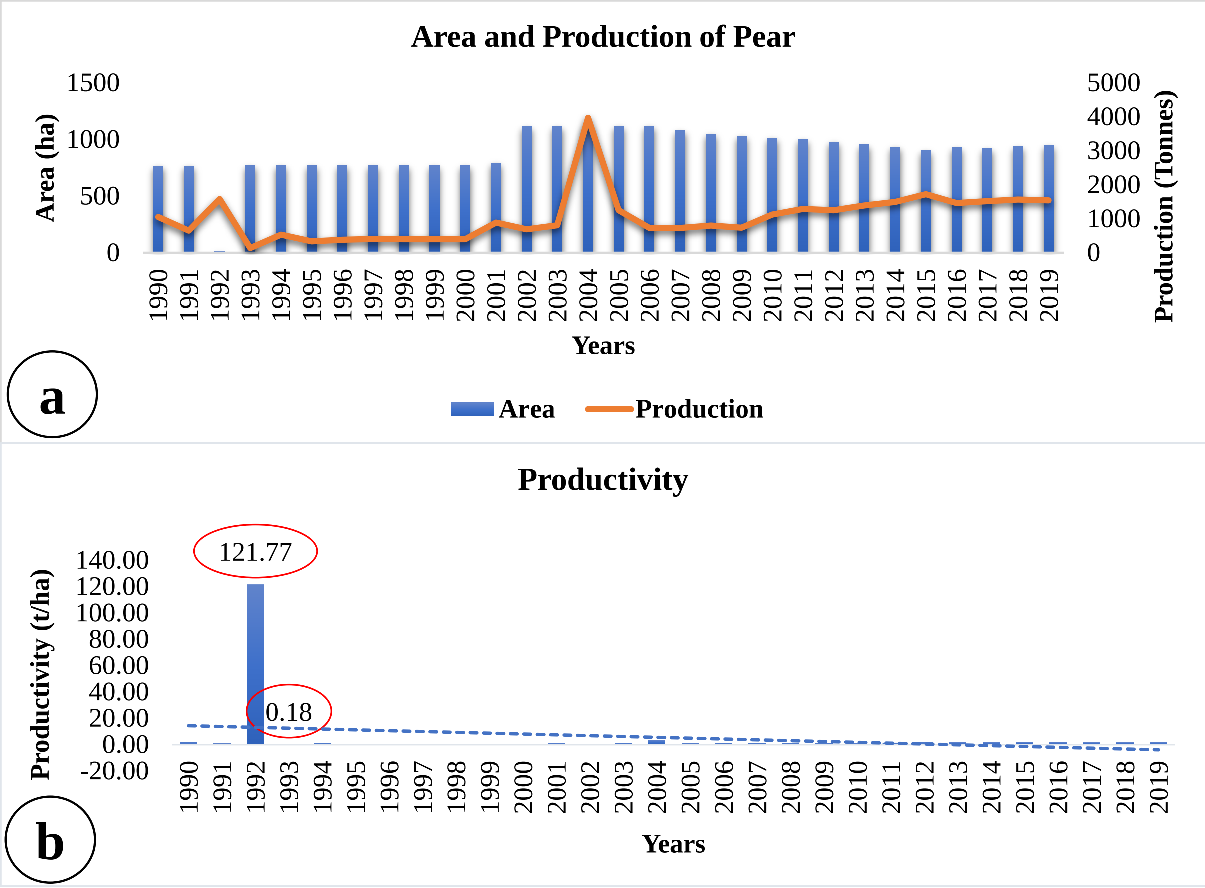

Figure 14 a&b. Variations in average acreage, production and productivity for Pear, district Solan, HP, (1990-2019)

Another important fruit crop is dry fruits. In this category, the major dry fruits of the district jointly contributed. However, the trend analysis of this category showed a very stimulating response, like in the initial years from 1990 to 2001, it maintained its acreage with small changes, but in year 2002, it suddenly dropped from 1219 ha to 287 ha, which is an abnormal observation. After 2002, it didn't show much variation. A similar trend was seen for the production of dry fruits. The starting years showed high fluctuations, while the later ones (from 2001 to 2019) represented the least changes (Figure 15a). However, dry fruit productivity has steadily declined over the last 30 years. The highest productivity of the dry fruits was recorded for the year 1993, i.e., 1.84 t/ha, and the lowest for 2001, which was 0.10 t/ha (Figure 15b).

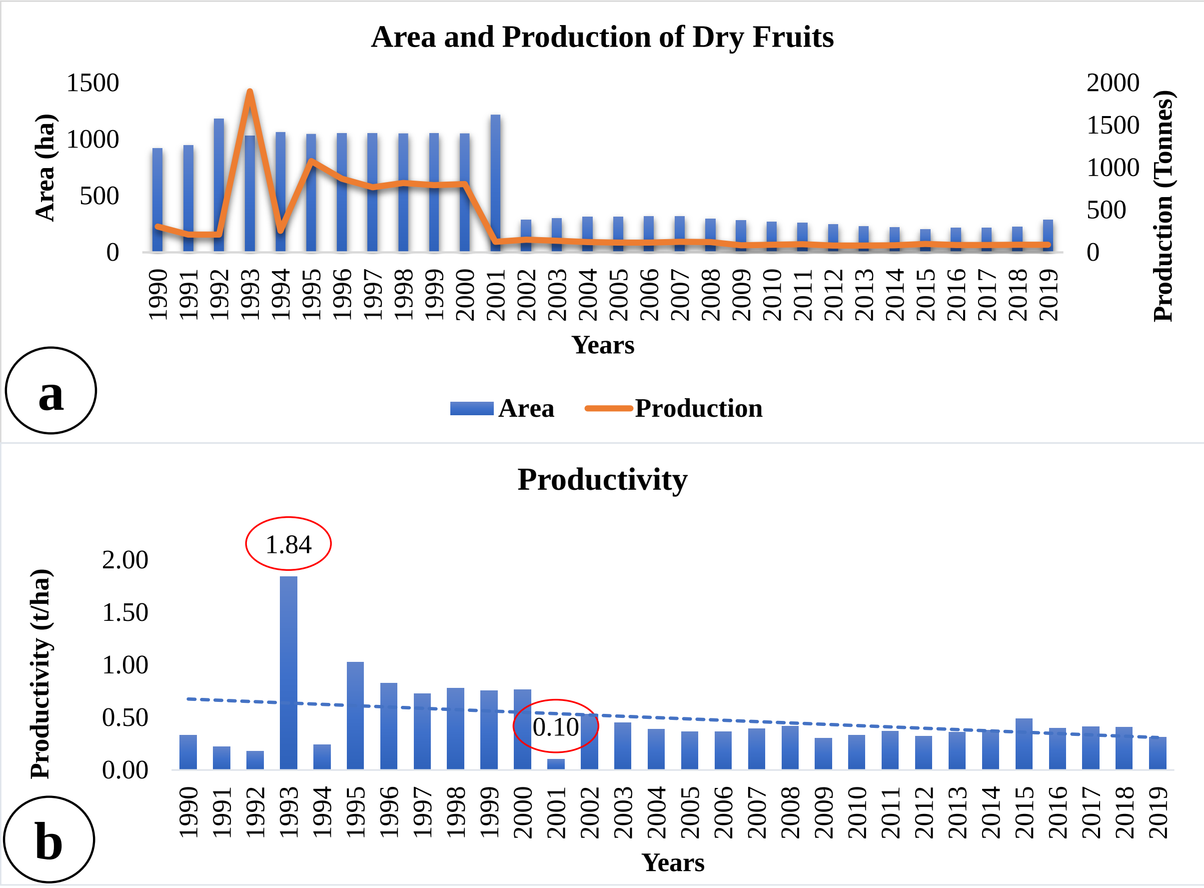

Figure 15 a&b. Variations in average acreage, production and productivity for dry fruits, district Solan, HP, (1990-2019)

Apart from these temperate or subtropical fruit crops discussed above; citrus fruits also represent a major portion of the district. The first citrus crop is Orange, and the same analysis was also done for these crops. The acreage of this crop showed a decreasing trend as the initial years from 1990 to 2010 did not show many changes, but the latter one showed a decrease. The acreage in 1990 was 242 ha, which remained 173 ha in 2019. Respectively, the production of Orange showed an increasing trend. Like in 1990, it was only 2 t, but in 2019, it was increased to 72 t. This abrupt increase was seen from 2002 onwards, as shown in Figure 16a. The productivity of Orange has increased significantly in the 30-year history of the district (Figure 16b).

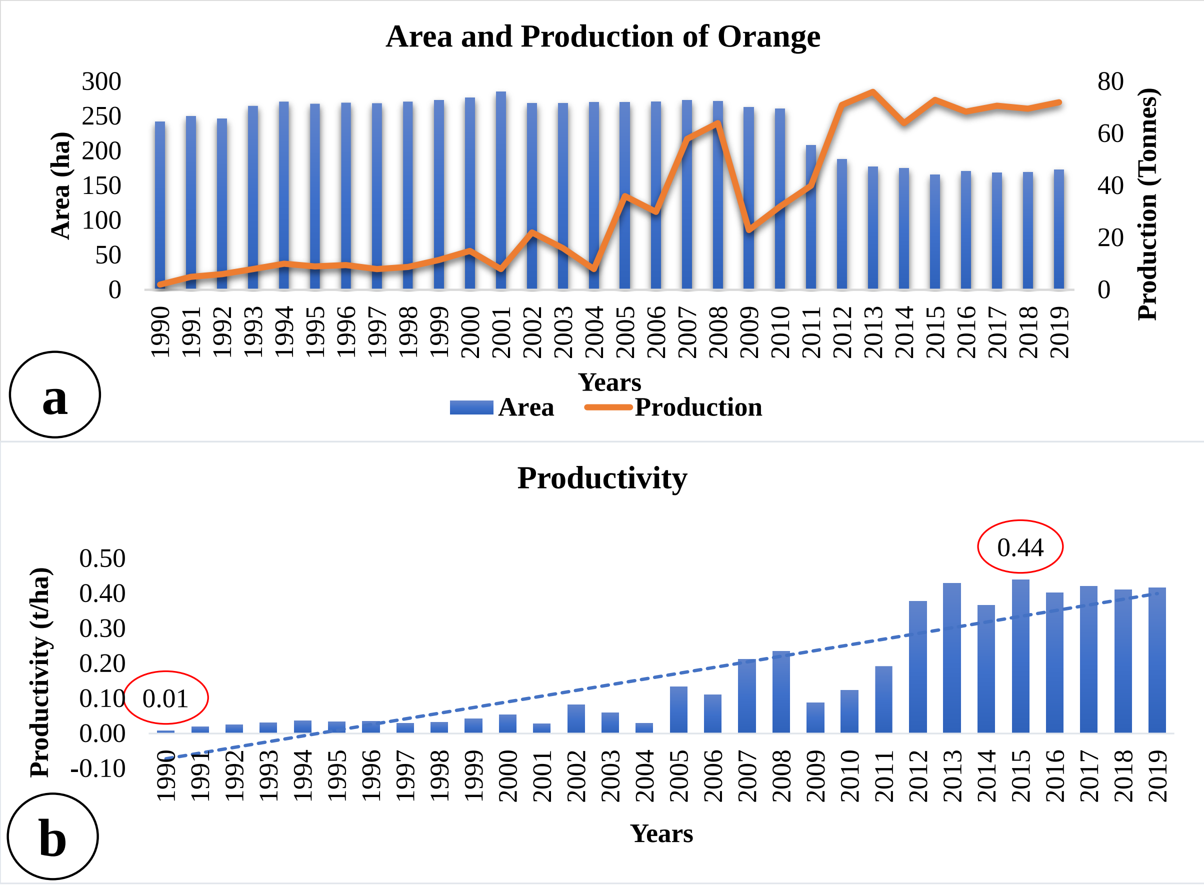

Figure 16 a&b. Variations in average acreage, production and productivity for Orange, district Solan, HP, (1990-2019)

Malta are the important citrus crops in the Solan district and are highly suited for the warm climate. The acreage of this crop was high in the year 1990, which started increasing in 1995 and then started decreasing in the mid of 2002, from where it again increased gradually. But in comparison to the initial year, it has decreased in 2019. The highest acreage was seen in 1995 and the lowest in 2002 and 2003, i.e., 25 ha and 6 ha, respectively. The production of this crop was increased from 1 t to 18 t from 1990 to 2019 (Figure 17a). However, the trend of production was irregular, showing abrupt change for many years. The productivity of the Malta showed an increasing trend. As the initial nine-year form from 1990 didn't show much variation, but the middle years had the highest productivity. After minor fluctuations at various intervals, it continuously increased from 2004 to 2019 (Figure 17b). However, the lowest productivity was recorded for the year 1990, i.e., 0.05 t/ha, whereas the highest was for 2002, which was 6.50 t/ha.

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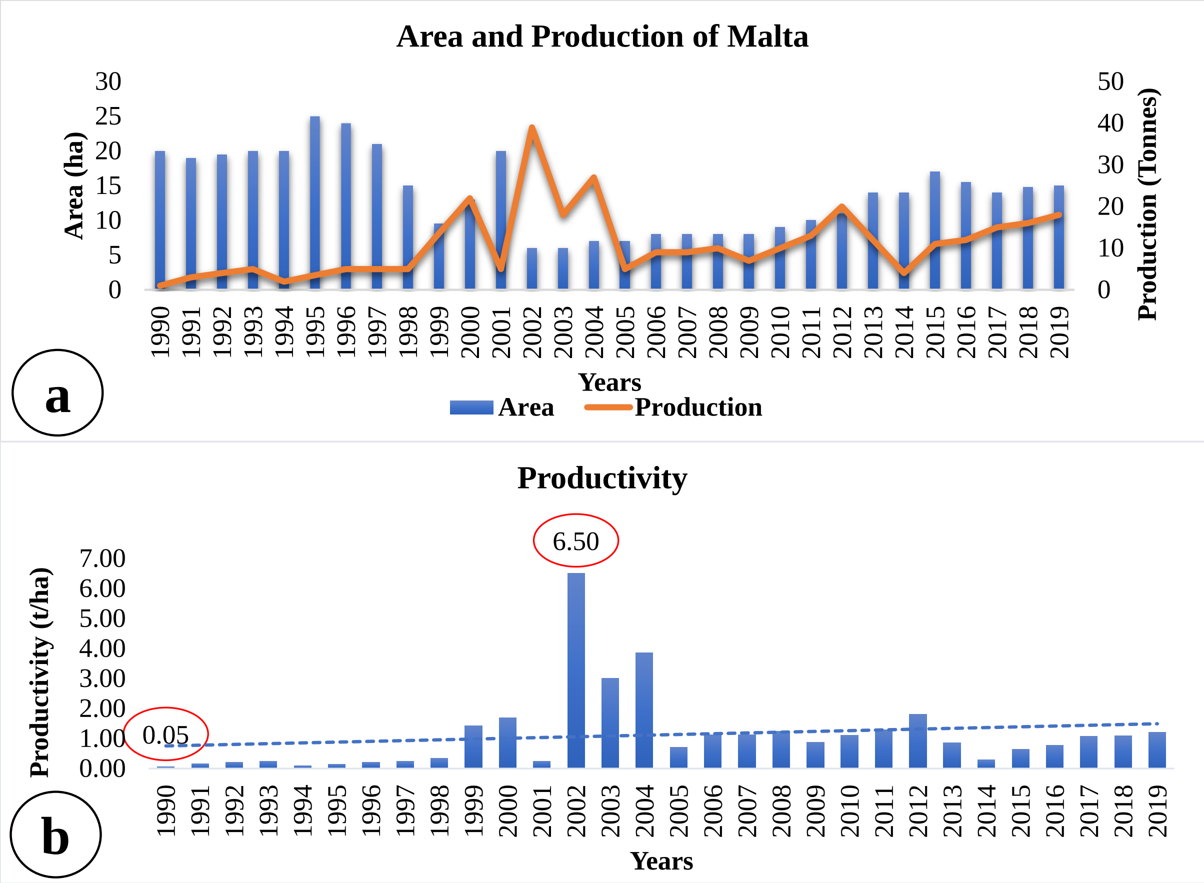

Figure 17 a&b. Variations in average acreage, production and productivity for Malta, district Solan, HP, (1990-2019)

During the data analysis of Kagzi Lime, it was revealed that there were abnormal variations in the data. The acreage of this crop showed slight variations till 2001; subsequently, acreage dropped unexpectedly from 3116 ha to 350 ha. After 2002, acreage increased slightly and remained at 516 ha in 2019. In contrast, the production starts dropping from 1990 to 1996 and then increases unexpectedly, which is approximately 100 times more than the initial year (Figure 18a). At the same time, the productivity of the Kagzi lime also showed a significant increase. The lowest productivity was seen for the year 1993 and the highest for 2015, at 0.0001 t/ha and 1.00 t/ha, respectively (Figure 18b).

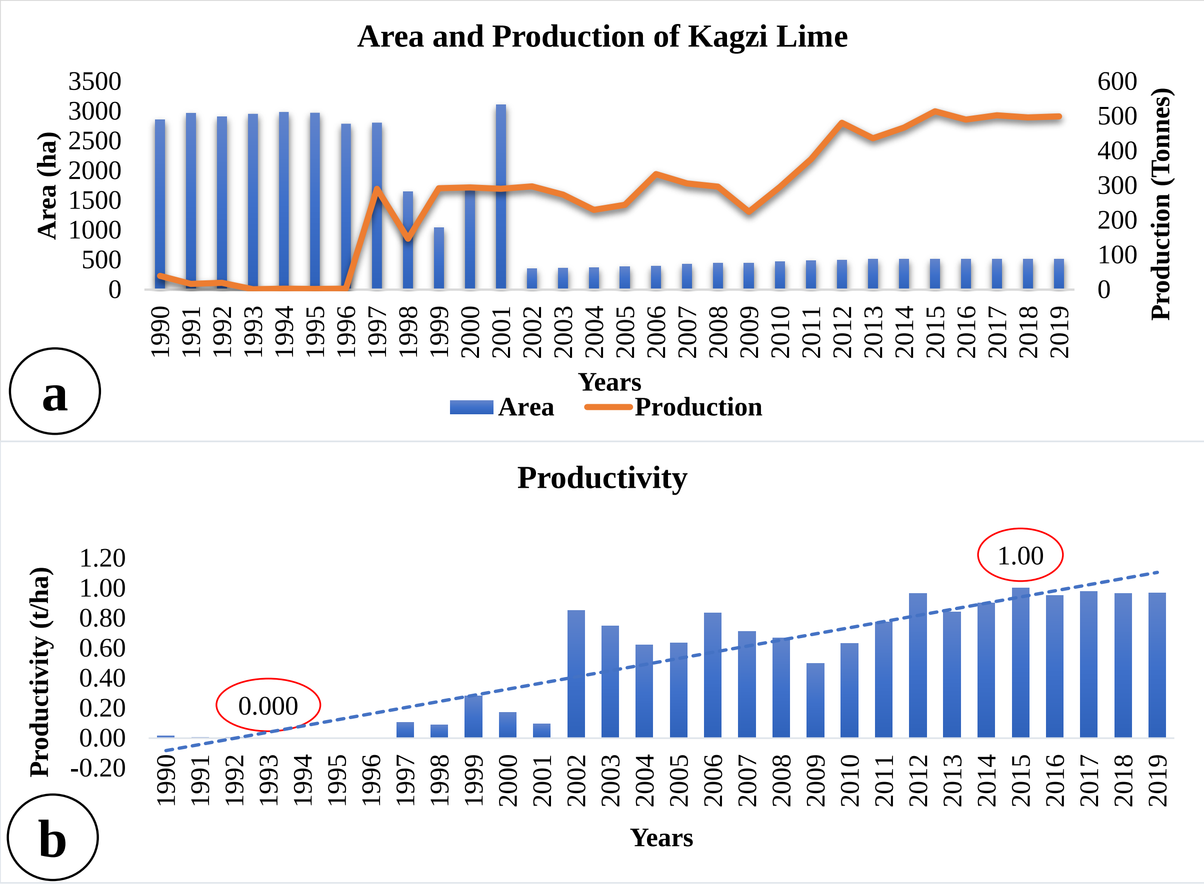

Figure 18 a&b. Variations in average acreage, production and productivity for Kagzi lime, district Solan, HP, (1990-2019)

The next citrus crop is Galgal, and the acreage of this crop showed a decreasing trend in the Solan district. However, there was a slight variation in acreage from 1997 to 2002, after which it was stable till 2019. The analysis of production data revealed an intermittent trend with fluctuations for various years. In 1993, it decreased to 5 t, which slightly went up to 18 t in 1996, but after that it increased significantly to 385 t. Then again, it stabilised from 2012 and persisted to 272 t in 2019 (Figure 19a). Similarly, the productivity of Galgal also increased drastically in the 30 years of history, as shown in Figure 19b. The lowest productivity was found in the year 1993 (0.02 t/ha) and the highest in 2015 (1.72 t/ha).

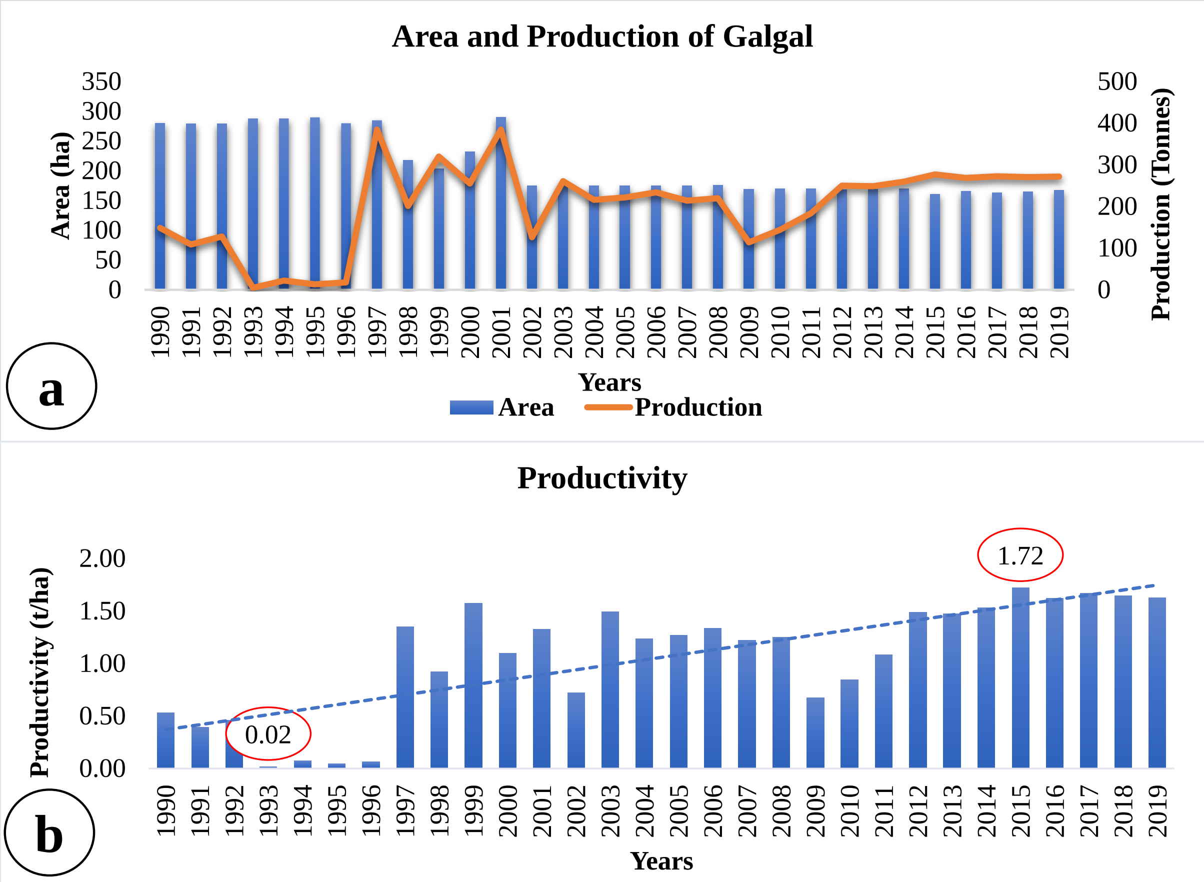

Figure 19 a&b. Variations in average acreage, production and productivity for Galgal, district Solan, HP, (1990-2019)

Another important crop is Mango. The data analysis revealed an increasing trend for the acreage. Likewise, the production didn't show variations till 1995, and after that it started increasing continuously till 2019. In 1990, the production was 39 t, which increased to 1430 t in 2019. Similarly, the productivity of the crop also increased from 1990 to 2019 at the rate of 0.04 t/ha to 0.84 t/ha, respectively (Figure 20a). However, the lowest productivity was observed in the year 1993 and the highest in the year 2014 (as shown in Figure 20b).

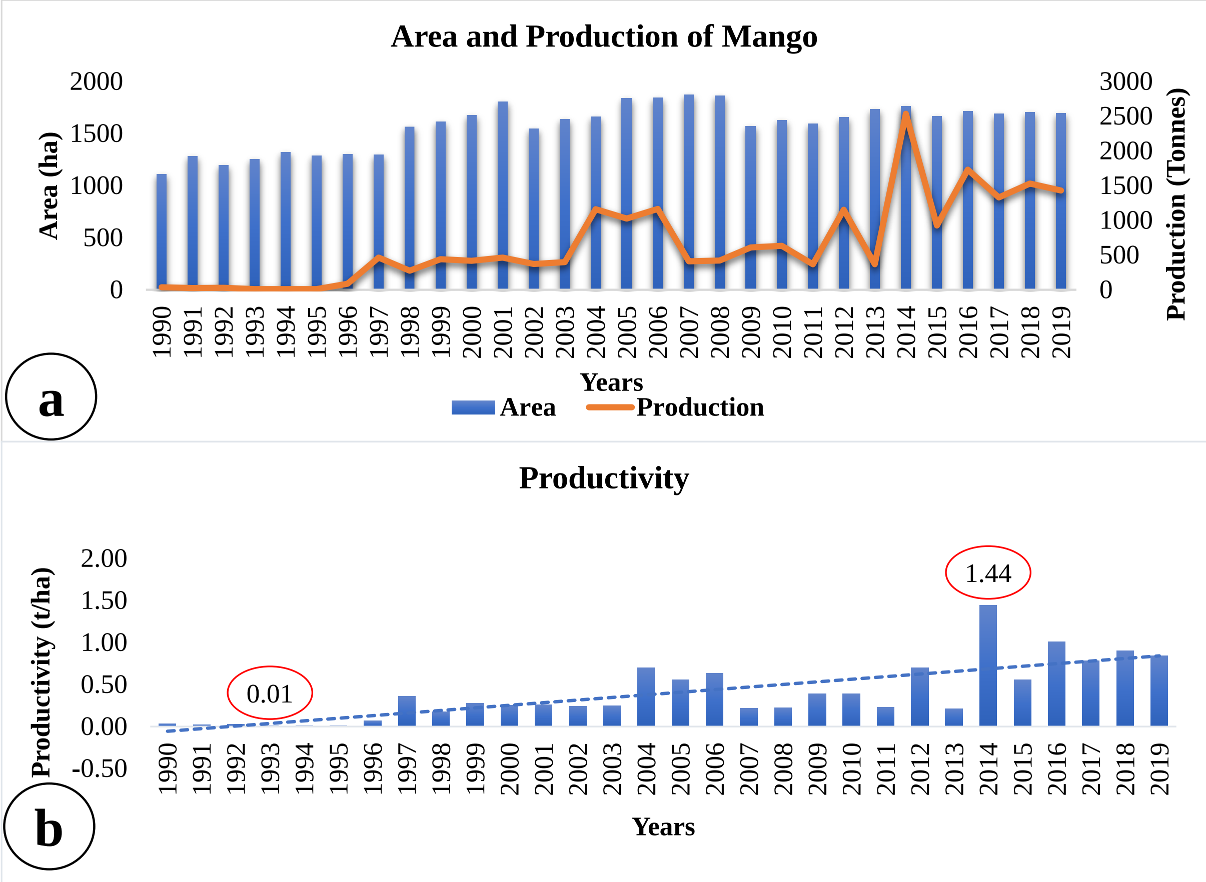

Figure 20 a&b. Variations in average acreage, production and productivity for Mango, district Solan, HP, (1990-2019)

The acreage and production of the Litchi crop showed a progressive trend. The acreage of Litchi gradually increased from 1990 to 2019, i.e., from 15 ha to 51 ha, respectively. A similar trend was observed for the production data, where production significantly increased from 5 t to 50 t, i.e., from 1990 to 2019 respectively, which is approximately 10 times higher (Figure 21a). The productivity of this crop also showed a visual increase in the 30 years of the period. The productivity increased from 0.33 t/ha to 0.98 t/ha in the years 1990 to 2019, respectively. However, the lowest productivity was observed for the year 1993 (0.16 t/ha) whereas the highest was for 2005 (1.21 t/ha), as shown in Figure 21b.

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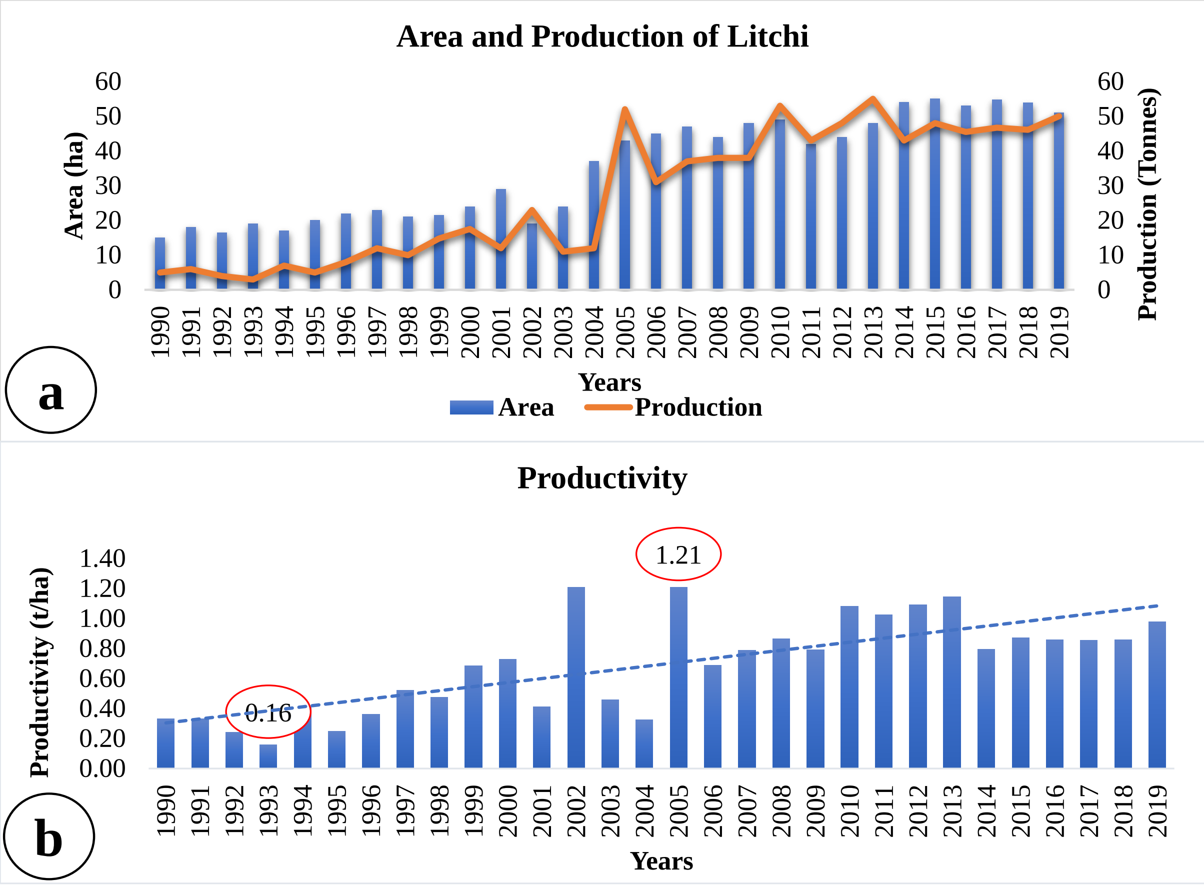

Figure 21 a&b. Variations in average acreage, production and productivity for Litchi, district Solan, HP, (1990-2019)

Apart from citrus crops, Guava is also an important fruit crop in the Solan district, which has a major role in terms of production and productivity. The analysis revealed that the acreage increased from 1990 to 2008, when it again started declining till 2019. But on comparing the first year, i.e., 1990, with 2019, it increased from 167 ha to 273 ha, respectively (Figure 22a). A similar trend was observed for the production, which progressively increased from 189 t to 580 t in the years 1990 and 2019 respectively. The productivity of the Guava from 1990 started increasing till 1997, but after that the productivity declined to 0.35 t/ha (lowest), then again increased to the highest of 2.19 t/ha in 2015. However, the trendline showed an increasing trend in the 30 years of data records (Figure 22b).

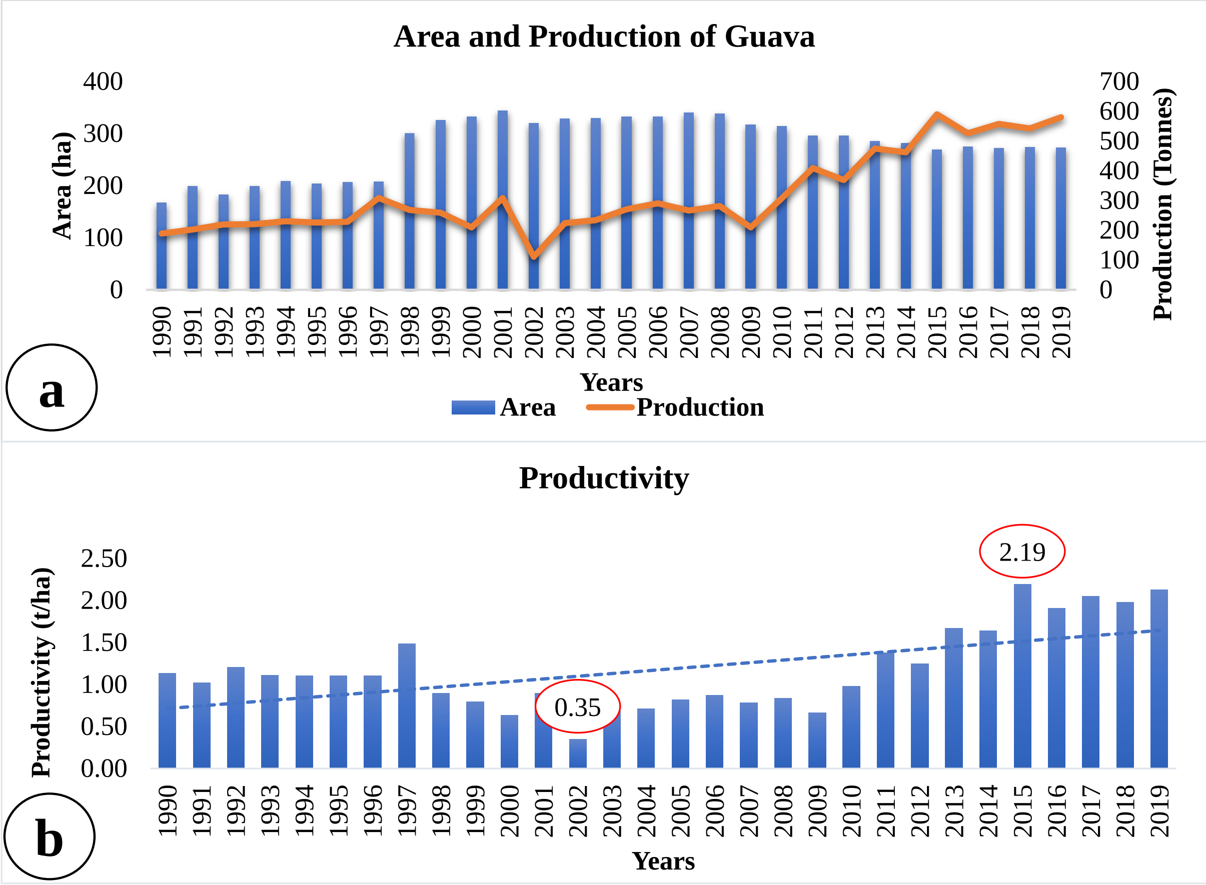

Figure 22 a&b. Variations in average acreage, production and productivity for Guava, district Solan, HP, (1990-2019)

The acreage and production fluctuations described above are based on the data that is currently available, although it is impossible to determine whether the variance is substantial from these graphs. To solve this, the Mann-Kendall Test was performed for all the fruit crops of the Solan district. The outcome from this model tells us about the mean, magnitude of crop yield and level of significance as mentioned in Table 5. Among all the studied crops, a highly significant increase in productivity was observed for 9 fruit crops, while for the remaining 4 crops it was non-significant. The productivity of Plum, Peach, Apricot, Pear, Orange , Kagzi Lime, Galgal, Mango and Litchi increased highly significantly at the rate of 0.080 t ha^{-1} yr^{-1}, 0.027 t ha-1 yr-1, 1.071 t ha^{-1} yr^{-1}, 0.048 t ha^{-1} yr^{-1}, 0.016 t ha^{-1} yr^{-1}, 0.040 t ha^{-1} yr^{-1}, 0.044 t ha^{-1} yr^{-1}, 0.028 t ha^{-1} yr^{-1}, and 0.027 t ha^{-1} yr-1, respectively (Table 5). The temperate fruits like Pear, Peach, Plum, and Apricot showed an increase in production at the rates of 0.172, 0.064, 0.018, and 0.018 t/ha per year during the last ten years (Rana et al., 2017).

Similarly, the productivity of Malta and Guava crops increased significantly in the Solan district, reaching 0.034 t ha-1 yr-1 and 0.034 t ha-1 yr-1, respectively. whereas the productivity of Apple was also increased non-significantly (0.007 t ha^{-1} yr^{-1}), while dry fruits in the district decreased non-significantly at -0.008 t ha^{-1} yr^{-1}. How much the climatic variations impacted the crops is explained in the next chapter, where a correlation with crop and climate has been calculated.

Table 4. Mann Kendall Test Results – Crop Yields for Fruit Crops (1990-2019)

Fruits Productivity	Mean	Sen's slope	*p*-value
Apple	0.309	0.007	0.075
Plum	8.095	**0.080**	**0.001**
Peach	0.471	**0.027**	**0.002**
Apricot	1.097	**1.071**	**0.001**
Pear	5.229	**0.048**	**0.001**
Dry Fruits	0.498	-0.008	0.171
Orange	0.169	0.016	**0.001**
Malta	1.158	**0.034**	**0.023**
Kagzi Lime	0.528	**0.040**	**0.001**
Galgal	1.720	**0.044**	**0.001**
Mango	0.404	**0.028**	**0.001**
Litchi	0.706	**0.027**	**0.001**
Guava	1.181	**0.034**	**0.026**

CHAPTER 5- CLIMATE AND CROP CONNECTION

To observe the relationship between the climate and the crop, how much these climatic variables impacted the crop yield in the Solan district was unknown. A Multivariate Linear Regression Analysis was done for all crops where the Pearson Coefficient and *p*-value were calculated for each climatic variable. During the pre-flowering stage, the crop productivity of only five crops were significantly impacted by the climatic variables which indicates that these climatic variables do not impact the productivity of the crop. Apple showed a significant negative moderate correlation was seen with the average minimum and diurnal temperature along with significant *p* value which collectively impacted the crop by 25%. Malta showed a highly significant strong positive correlation with the average diurnal temperature i.e., .651 with *p* value of .000 where the crop productivity was 52.6% impacted. Similar observation was seen for the Kagzi Lime, where a moderate negative correlation was seen with diurnal temperature i.e., .360 (*p* value of .025) and the overall impact of the climate was 30.8%. Likewise for Mango, a significant correlation was observed with the diurnal temperature only which collectively impacted the crop by 37%. Guava during pre-flowering stage showed a strong negative correlation with the average maximum temperature i.e., -.526 with highly significant *p* value (.001). The key highlight of this phenological stage is that Guava was highly impacted (55.3%) as shown in the Table 6. The other crops during this phenological stage did not show any remarkable changes or correlations.

Table 5. Multivariate Linear Regression Analysis-Crop Yields and Climatic Parameters, (1990- 2019) for Pre-Flowering. Abbreviations used: Min T: Minimum temperature, Max T: Maximum temperature, DT: Diurnal temperature, RF: Rainfall

S No.	Crops	Variable / Statistics	Pre-Flowering					
			Max T	Min T	DT	RF	R^2	% Change
1.	Apple	Coefficient *p*-value	.270 .074	**.313** **.046**	**.316** **.045**	-.019 .460	.250	**25**
2.	Plum	Coefficient *p*-value	-.080 .337	-.174 .179	.106 .289	.173 .180	.119	11.9
3.	Peach	Coefficient *p*-value	.069 .358	.047 .403	.295 .057	.164 .193	.340	34
4.	Apricot	Coefficient *p*-value	-.073 .351	-.030 .438	.197 .148	.221 .120	.399	39.9
5.	Pear	Coefficient *p*-value	-.139 .231	-.151 .213	-.042 .413	.097 .305	.037	3.7
6.	Dry Fruits	Coefficient *p*-value	-.092 .314	.052 .393	-.040 .416	.096 .308	.067	6.7
7.	Orange	Coefficient *p*-value	-.218 .123	-.041 .415	.099 .301	.267 .077	.620	6.2

8.	Malta	Coefficient *p*-value	.440 .007	.132 .243	**.651** **.000**	.003 .494	.526	**52.6**
9.	Kagzi Lime	Coefficient *p*-value	.074 .349	-.173 .180	**.360** **.025**	.116 .271	.308	**30.8**
10.	Galgal	Coefficient *p*-value	.057 .383	-.089 .319	.288 .061	.080 .337	.214	21.4
11.	Mango	Coefficient *p*-value	.100 .299	-.176 .176	**.412** **.012**	.093 .313	.370	**37**
12.	Litchi	Coefficient *p*-value	-.066 .365	-.134 .239	.197 .148	.245 .096	.290	29
13.	Guava	Coefficient *p*-value	**-.526** **.001**	-.054 .389	-.449 .006	-.047 .403	.553	**55.3**

For flowering stage, analysis revealed that the impact of climatic variables in terms of percent change was highest for Malta, where a very strong correlation was observed with the average maximum temperature i.e., .730 (having high significant *p* value) and diurnal temperature (.623). The overall impact of the climatic variable was 69.4% which is highest among all crops. The second most impacted crop during flowering stage was Guava which showed strong negative correlation with the average maximum and diurnal temperature with highly significant *p* values. In other words, the productivity of Guava was 56.5% impacted during flowering stage (Table 7). Apple was least impacted during this phenological stage which showed significant correlations with maximum temperature only impacted the crop by 20.7%. The other crops like plum, peach, apricot, pear, dry fruits, orange, kagzi lime, galgal, mango and litchi did not exhibit any significant correlations therefore, they are not much explained.

Table 6. Multivariate Linear Regression Analysis-Crop Yields and Climatic Parameters, (1990- 2019) for Flowering. Abbreviations used: Min T: Minimum temperature, Max T: Maximum temperature, DT: Diurnal temperature, RF: Rainfall

S No.	Crops	Variable / Statistics	Flowering					
			Max T	Min T	DT	RF	R^2	% Change
1.	Apple	Coefficient *p*-value	**.320** **.043**	-.137 .235	.271 .074	-.180 .170	.207	**20.7**
2.	Plum	Coefficient *p*-value	.061 .374	.010 .478	-.005 .491	.013 .472	.084	8.4
3.	Peach	Coefficient *p*-value	.118 .268	-.077 .343	.033 .431	.214 .129	.336	33.6
4.	Apricot	Coefficient *p*-value	.026 .445	.027 .443	-.101 .298	.130 .246	.369	36.9
5.	Pear	Coefficient *p*-value	-.083 .331	.096 .306	-.139 .232	.090 .317	.044	4.4
6.	Dry Fruits	Coefficient *p*-value	.130 .247	-.041 .415	.093 .312	-.190 .157	.083	8.3
7.	Orange	Coefficient *p*-value	.044 .409	.095 .309	-.134 .240	-.023 .451	.535	53.5

8.	Malta	Coefficient *p*-value	**.730** **.000**	-.178 .173	**.623** **.000**	-.366 .023	.694	**69.4**
9.	Kagzi Lime	Coefficient *p*-value	.258 .084	-.173 .181	.199 .146	-.128 .250	.314	31.4
10.	Galgal	Coefficient *p*-value	.207 .136	-.120 .264	.139 .231	-.080 .337	.254	25.4
11.	Mango	Coefficient *p*-value	.289 .061	-.196 .150	.228 .113	-.196 .149	.390	39
12.	Litchi	Coefficient *p*-value	.229 .112	-.047 .403	.127 .251	-.152 .212	.279	27.9
13.	Guava	Coefficient *p*-value	**-.631** **.000**	.171 .183	**-.680** **.000**	.265 .078	.565	**56.5**

Besides the pre-flowering and flowering stages, the productivity of the crop can also be impacted at the fruit setting stage. Because any fluctuation in the major climatic variables like temperature and precipitation will ultimately affect the productivity of a crop. As per the outcome from the Multivariate Regression Analysis model, only those correlations were discussed which was supported by the significant *p* values whereas, the correlations with high *p* values are nonsignificant and of lest importance. During fruit setting stage, the apple crop showed a significant moderate positive correlation with average maximum temperature with significant *p* value of .044 and the total impact in terms of percent change was 12.5%. A moderate negative correlation was observed with the average minimum temperature (having *p* value of .021). Hence, the plum crop was 18.6% impacted during this stage. Similar observation was seen for the pear crop where productivity was 16.5% impacted (Table 8). The average maximum and diurnal temperature showed moderate positive correlation with malta which collectively 16.2% impacted the crop productivity. For mango crop, the average minimum temperature showed strong negative correlation i.e., -.607 with high significant *p* value (.000). Because of this highly significant correlation, the crop productivity was impacted most among all crop during the fruit setting stage i.e., 39.2%. However, for guava, the average maximum and diurnal temperature showed moderate negative correlation along with high significant *p* values and the crop productivity was 23.9% impacted by the climatic variables (Table 8). However, the remaining crops was least impacted or showed nonsignificant correlations.

Table 7. Multivariate Linear Regression Analysis-Crop Yields and Climatic Parameters, (1990- 2019) for Fruit setting. Abbreviations used: Min T: Minimum temperature, Max T: Maximum temperature, DT: Diurnal temperature, RF: Rainfall

S No.	Crops	Variable / Statistics	Fruit Setting					
			Max T	Min T	DT	RF	R^2	% Change
1.	Apple	Coefficient *p*-value	**.317** **.044**	.154 .208	.162 .197	-.090 .318	.125	**12.5**

2.	Plum	Coefficient	.044	**-.374**	.293	-.194	.186	**18.6**
		p-value	.409	**.021**	.058	.153		
3.	Peach	Coefficient	.203	-.155	.281	.061	.140	14
		p-value	.141	.206	.066	.375		
4.	Apricot	Coefficient	.099	-.176	.209	-.023	.079	7.9
		p-value	.301	.176	.134	.453		
5.	Pear	Coefficient	-.137	**-.334**	.111	-.169	.165	**16.5**
		p-value	.235	**.036**	.280	.186		
6.	Dry Fruits	Coefficient	.175	.159	.040	-.200	.081	8.1
		p-value	.177	.201	.416	.144		
7.	Orange	Coefficient	.159	.080	.087	-.204	.108	10.8
		p-value	.201	.336	.324	.140		
8.	Malta	Coefficient	**.314**	-.123	**.350**	-.140	.162	**16.2**
		p-value	**.046**	.259	**.029**	.230		
9.	Kagzi Lime	Coefficient	-.173	-.357	.100	.014	.149	14.9
		p-value	.180	.026	.299	.470		
10.	Galgal	Coefficient	-.187	-.280	.033	-.009	.108	10.8
		p-value	.161	.067	.431	.481		
11.	Mango	Coefficient	-.220	**-.607**	.228	.007	.392	**39.2**
		p-value	.121	**.000**	.113	.486		
12.	Litchi	Coefficient	.033	-.046	.070	-.078	.073	7.3
		p-value	.432	.405	.357	.341		
13.	Guava	Coefficient	**-.466**	-.001	**-.356**	.091	.239	**23.9**
		p-value	**.005**	.497	**.018**	.316		

CHAPTER 6 – CONCLUSION

To capture the nerve of the climate in the Solan district, three exercises were done, which included climate trend analysis (for average maximum, minimum, diurnal temperature, and annual rainfall); Mann-Kendall trend analysis (for acreage and production); and multivariate regression analysis. The analysis of 30 years of climate and crop data revealed that during the pre-flowering stage, no significant variations were seen. Whereas for flowering stages, the minimum temperature increased significantly by 0.151°C per year, whereas the diurnal temperature during these phenological stages showed a highly significant decrease of -0.158°C per year. The annual rainfall during the flowering stage was also significantly decreased, at -0.082 mm per year. Although, for the fruit setting stage, the average minimum temperature decreased significantly at the rate of -0.031°C per year.

Findings from Mann-Kendall trend analysis revealed a highly significant increase in productivity for Plum, Peach, Apricot, Pear, Orange/Kinow, Kagzi Lime, Galgal, Mango and Litchi. A significant increase was seen for Malta, and Guava whereas non-significant variation was observed for Apple and dry fruits. Multivariate linear regression analysis for crop yields and climatic parameters revealed that the highest impact of climatic variables was observed for Malta and Guava, i.e., 44.4% and 42%, respectively, for the pre-flowering stage. During the flowering stage, the impact of climatic variables was highest for Malta (59.9%), followed by Guava (57.9%), Orange (49.6%), and Apricot (30.9%). whereas for the fruit setting stage, Mango had the highest percentage impact (60%), followed by Guava (33%), and Kagzi lime (29.5%). In general, each developmental stage of fruit crops is influenced by climatic variables, but in a positive way, which increases fruit crop productivity in the Solan district.

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