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Adapting fruit crops to climate change: Strengthening resilience and implementing adaptation measures in fruit crops

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Abstract
Climate change presents significant challenges to the global production of fruit crops, impacting both their productivity and quality. Effects of climate change are becoming prominent recently in form of rising temperature, uneven and altered precipitation patterns and an increase in extreme weather events are becoming noticeable. These changes directly influence maturity and development of fruit crops, leading to shifts in phenology, modifications in fruit yield, and alterations in fruit composition. Heat stress during flowering and fruit set stages can have detrimental effects on fruit production, while irregular rainfall patterns can disrupt pollination and elevate the risk of pests and diseases. Elevated levels of carbon dioxide can also impact the quality characteristics of fruits.
To ensure the continued production and sustainability of fruit crops, building resilience becomes of utmost importance. Resilience involves the capacity of fruit crops to adapt and recover from the impacts of climate change while maintaining productivity and quality. Various strategies can be implemented to enhance resilience in fruit crops, including the breeding and selection of climate-resilient varieties, the adoption of improved agronomic practices, the implementation of efficient irrigation systems, and the utilization of precision farming techniques. Institutional support and policy frameworks play a critical role in promoting resilience within fruit crop systems. It is essential to prioritize interdisciplinary research collaborations among scientists, farmers, policymakers, and stakeholders to develop effective adaptation and mitigation strategies. These collaborations facilitate the exchange of knowledge, experiences, and innovations, contributing to the development of robust resilience in fruit crop systems.

Keywords: Climate change, resilience, mitigation, fruit, varieties

Introduction

Climate change

As mentioned in Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as the alteration of climate conditions that can be attributed directly or indirectly to human activities. These activities lead to changes in the composition of the global atmosphere and are in addition to the natural variability of climate observed over a comparable time frame.
The Intergovernmental Panel on Climate Change (IPCC, 2007) [8] defines climate change as a modification in the state of the climate, identifiable through statistical tests that demonstrate changes in the mean and/or variability of climate properties. These changes persist for an extended period, typically spanning decades or longer.

The greenhouse effects

Greenhouse gases such as CO_2, methane, CO, CFCs, nitrous oxide, and others play a critical role in the Earth's atmosphere. These gases do not absorb incoming short waves directly, but they do absorb outgoing long waves that are reflected from the Earth's surface, resulting in the warming of the planet.
The greenhouse effect can be categorized into two sources:

a) The natural greenhouse effect occurs as a natural process in the Earth's atmosphere.
b) The enhanced greenhouse effect, which is influenced by human activities and results in increased greenhouse gas concentrations, intensifies the warming effect.

The presence of greenhouse gases (GHGs) is crucial for sustaining life on Earth, differentiating it from planets like Venus or Mars. Without GHGs, the average temperature would be approximately 30 °C colder than it is today. Among the GHGs, carbon dioxide (CO_2) plays a significant role in regulating Earth's temperature, contributing to the support of life. The enhanced greenhouse effect is a consequence of the increased concentration of GHGs in the atmosphere. As a result, more of the sun's heat energy is trapped in the Earth's atmosphere, leading to higher temperatures. It is important to note that this effect is primarily driven by human activities, known as anthropogenic activities.

Climate change in India: The current scenario and implications

India, ranked fourth among the countries most affected by climate change in 2015, experiences profound consequences as a result of this global phenomenon. As a country of immense importance to the global community, it is crucial to recognize that disruptions within any part of India's land system can have far-reaching implications for the entire ecosystem. Given India's substantial population and remarkable biodiversity, it becomes imperative to remain vigilant. The evident and concerning effects of climate change in India further underscore the need for proactive measures and heightened awareness.

From 1901 to 2018, the average temperature has already increased by 0.7 degrees Celsius. Projections indicate a possibility of a further rise of approximately 4.4 degrees Celsius in average temperature by the end of the twenty-first century. (Krishnan *et al*., 2020) [9].

Deepa and Shiyani (2013) [4] at Junagadh Agricultural University in Junagadh have categorized various districts based on their vulnerability to climate change. Among the selected districts, Amreli and Ahmedabad were identified as highly vulnerable to climate change, while Vadodara, Junagadh and Panchmahal were found to have lower vulnerability levels.

Influence of temperature

Elevated temperatures can have adverse effects on pollination, leading to increased incidences of flower abortion and fruit drop. These extreme temperatures often cause delays in fruit maturation and diminish fruit quality. Additionally, high temperatures can hinder proper colour development in fruits. Furthermore, the occurrence of various physiological disorders becomes more pronounced in fruit crops under high-temperature conditions. Examples include spongy tissue in mangoes, fruit cracking, and black spot in custard apples. The specific chilling requirements of pome and stone fruits are also influenced by high temperatures, resulting in earlier dormancy breaking than usual.

Spongy tissue in mangoes becomes more severe when the temperature surpasses 40.5 °C. However, mango trees are capable of tolerating temperatures as high as 48 °C for short durations, although they have limited tolerance to cold temperatures (Mukherjee, 1953) [11].

Flower bud initiation is withdrawn in many plants due to low temperatures. Dormancy breaking will be earlier. (Kumar and Kumar, 2007) [10].

Mango trees exhibit a propensity for vegetative growth, and as temperatures increase, they tend to produce more leaves, subsequently affecting the flowering phenology. It is noteworthy that panicles that emerged later in the season exhibited a higher percentage of hermaphrodite flowers (possessing both stamen and carpel), coinciding with periods of extreme temperatures. (Balogoun *et al*., 2016) [3].

The variations in nutritional content, physical attributes and biochemical parameters observed in dragon fruit could be attributed to environmental factors, including light intensity, light quality, temperature, humidity and other relevant conditions. (Parmar and Karetha, 2020; Parmar and Karetha, 2021) [13, 14].

Citrus cultivation spans from sea level to elevations of up to 2100 m. However, for optimal growth, a temperature range of 2 °C to 30 °C is considered ideal. Prolonged exposure to temperatures below 0 °C can cause injury to the citrus trees, and growth is negatively affected when temperatures drop below 13 °C. Dry root rot has emerged as a significant global concern, particularly in conditions of stress and climate change. This condition poses a serious threat to citrus crops worldwide (Said *et al.* 2022) [18].

Influence of irrigation water

By the year 2025, it is expected that a majority of irrigated regions in India will experience an increased demand for water. Furthermore, global net irrigation requirements are projected to rise by approximately 3.5-5% by 2025 and 6-8% by 2075, compared to the scenario without climate change. In the apple-growing areas of Himachal Pradesh, it was estimated that approximately 80% of the decrease in apple yield could be attributed to a shortage of irrigation water, while the remaining 20% was influenced by a high evaporation rate. Additionally, these regions experienced a decline in the number of chill unit hours, which are crucial for apple production. (Singh *et al*., 2016) [19].

Impact of relative humidity

Fruit set could be adversely affected by changes in relative humidity levels and could result in excessive fruit drops in citrus fruits such as oranges, mandarins, and various temperate and subtropical fruit crops. Effects on fruit set as poor pollen germination resulting due to desiccation or drying of stigmatic fluid could be seen due to low and high humidity. The higher intensity of relative humidity was also found to result in greater infestation of mango hopper and higher incidence of powdery mildew.

Influence of rainfall

Pre-monsoon showers have detrimental effects on crops such as grapes and dates, leading to the complete destruction of the harvest. Rainfall during the flowering period washes away pollen from the stigma of flowers, resulting in poor or no fruit set. In Gujarat, mango production suffered a severe loss of 80-90 percent due to unseasonal rain followed by a heavy dew attack during the blossoming season. These adverse weather conditions led to reduced fruit set, increased fruit drop during the pea stage, and a higher incidence of sooty mould and powdery mildew in mango crops. (Varu *et al*., 2015) [21].

Patil *et al*. (2015) [16] found that rainfall is negatively correlated with the production of all fruits except grapes and apples were positively correlated. If rainfall increases the productivity of apple and grape also increase. With reference to minimum temperature and production the sapota and guava with 38.11% and 35.23% are positively correlated but grape and pineapple are negatively correlated with 65% and 44%. The correlation between production and max temperature of banana and mango showed the highest correlation with 39.55% and 39.37% and there was a negatively correlated in the case of grapes with 66.99%.

Influence of frost

In temperate climates, spring frosts pose a significant threat to plants as they have the potential to damage blossoms, consequently impacting fruit set and development. Damage is mainly confined to the plant parts near the ground level as it is the coldest place. Freezing results in the inner sap-carrying tissues in young bark to be shattered and often the bark of the young trees is killed.

Yadollahi (2011) [23] investigated passive and active protective methods for the losses reduction due to frost stresses in grapes cultivated at Shahrekord (Iran) and observed that treatments using heaters were significantly effective in comparison to rest of the treatments applied during the first year of study due to lack of frozen stresses. Nevertheless, the treatment of the Bordeaux mixture was the best method for the reduction of damage in grapes, since there were freezing stresses on the growth of grapes.

Influence of CO_2 on fruit crops

There are indications that pests, including aphids and weevil larvae, exhibit a favourable response to elevated levels of carbon dioxide (CO_2) and changing climatic conditions. These changes in climatic parameters also contribute to an increased risk of new pest incursions. In strawberries, a 12% and 35% decrease in fruit yield was observed at elevated CO_2 and high temperatures when provided with low and high nitrogen, respectively. Fewer inflorescences and reduced umbel size during flower induction has resulted in the reduction of fruit yield at elevated CO_2 and high temperatures.

Impact of pruning on different fruit crops

The yield and yield attributes and quality parameters were significantly influenced by various levels of pruning. Maximum fruit yield (2.44 t/ha), average weight of fruit (174.11 g), fruit length (6.59 cm), fruit girth (6.83 cm), maximum pulp weight (104.45 g), pulp: Seed ratio (8.18), pulp: Rag ratio (1.82), minimum number of seed (25.55), weight of seed (13.42 g), maximum total sugar (22.33%), reducing sugar (18.47%), non-reducing sugar content (3.83%), ascorbic acid (21.55 mg/100g), TSS (22.31°Brix) and minimum acidity (0.25%) were noted in medium pruning at 20 cm (P3). Whereas, minimum days to flower initiation (73.41) were recorded with unpruned trees (P_1) (Parsana *et al*., 2023) [15].

Climate resilience

Climate resilience refers to the ability of a socio-ecological system to withstand external stresses caused by climate change while maintaining its functionality. It involves two key aspects:

1. **Absorbing stresses:** The system should be able to absorb and cope with the impacts of climate change without significant disruption to its functioning.
2. **Adaptation and improvement:** The system should be capable of adapting, reorganizing, and evolving into more sustainable configurations that enhance its resilience and preparedness for future climate change impacts.

In the horticultural sector, several adaptation measures can be implemented to effectively manage climate change in the future.

Diversification in crop cultivation

The most viable solution to address the challenge of insufficient chilling is the development of low-chill cultivars. However, breeding such cultivars presents significant challenges. To expedite the breeding process and facilitate the development of suitable cultivars for major fruits, modern biotechnological approaches are necessary to map the genetic factors influencing chilling requirements. Additionally, the introduction and adaptation of low-chill cultivars for crops like apple, peach, pear, and plum can be implemented in specific regions of lower hills and North Indian plains, enabling their commercial cultivation within a reasonable time frame. But, it could also mean diversification in products as products processed enables producers to use almost all the products even if they are of low grade and could not be marketed as such; diversification into some annual crops or livestock and even diversification of the landscape (consider swales, windbreaks, wildlife strips, the "edge effect," or ponds).

Crop improvement strategies

A. Climate-ready crop varieties

Fruit crops such as Dragon fruit, Kair, Phalsa, Pummelo, Beal, Wood apple, Aonla, Karonda, barbarous cherry, and pomegranate exhibit lower moisture demand and have reduced transpiration rates. These crops are relatively less affected by fluctuations in temperature, with their flowering and fruiting processes remaining relatively stable.

B. The implementation of low-chill cultivars for pome fruits, stone fruits and nut fruits is being explored as a viable approach

The most viable solution to address the challenge of insufficient chilling is the development of low-chill cultivars. However, breeding such cultivars presents significant challenges. To expedite the breeding process and facilitate the development of suitable cultivars for major fruits, modern biotechnological approaches are necessary to map the genetic factors influencing chilling requirements. Additionally, the introduction and adaptation of low-chill cultivars for crops like apple, peach, pear, and plum can be implemented in specific regions of lower hills and North Indian plains, enabling their commercial cultivation within a reasonable timeframe.

C. Efforts are underway to develop novel genotypes that possess resistance to high temperatures and elevated concentrations of carbon dioxide (CO_2)

Elevated levels of carbon dioxide (CO_2) have a notable impact on trees, resulting in improved productivity through various mechanisms such as increased water use efficiency, higher photosynthetic rates, enhanced sugar accumulation, and greater biomass production. Despite the negative implications of rising temperatures and CO_2 levels in the atmosphere, certain crops also benefit from these changes. For instance, C4 plants exhibited an increased photosynthesis rate compared to C3 plants in response to higher temperatures. However, it was observed that the concentration of CO_2 in C4 plants quickly reaches saturation, whereas photosynthetic response rates in C3 species continue to rise even with several hundred ppm of CO_2 increase.

D. Marker-assisted selection and develop transgenic crops to confer resistance against biotic and abiotic factors

Marker-assisted selection and the development of transgenic crops with resistance to biotic and abiotic factors are important strategies in crop improvement. These methods aim to enhance genetic traits that contribute to climate resilience, such as increasing yield, improving resource use efficiency (including radiation, water and nutrient utilization) and enhancing stress tolerance. To achieve these goals, genetic enhancement approaches are employed, utilizing various sources of genetic variation. These include natural variations found in germplasm resources, induced variations through mutant resources and the application of genomic-assisted breeding techniques, including the utilization of CRISPR-Cas technology for crop improvement.

Overall, these genetic enhancement approaches play a vital role in developing climate-resilient crops by targeting specific traits and leveraging advancements in genetic research and biotechnology to enhance crop productivity and adaptability to changing environmental conditions.

E. The focus is on developing genotypes that possess resistance to heat and drought conditions.

Efforts are being made to develop cultivars, varieties, and rootstocks that exhibit tolerance or resistance to the effects of climate change.

Ali and Ibrahim (2019) [2] studied the fruit quality characteristics of cultivar Anna apple grafted on different rootstocks and found that the maximum fruit width (75.65 mm), fruit length (77.30 mm), fruit weight (221.42 g), fruit volume (238.71 cm^3), fruit flesh firmness (18.6 lb/cm^2) and TSS (15.4%) were obtained when Anna apple cultivar trees were grafted on MM 111 rootstocks. However, the highest titratable acidity content (0.77%) was found on Anna apple cultivar trees that were grafted on M9 rootstock.

Ghule *et al*. (2019) [6] carried out a field experiment The objective of the study was to investigate the influence of different rootstocks (Dogridge, 110 R, and 140 Ru) on graft success and growth parameters in Thompson Seedless, Manjari Medika and Manjari Kishmish grape varieties. The findings demonstrated noteworthy results regarding trunk girth, number of canes/vines, and leaf area. Specifically, when Thompson Seedless and Manjari Medika were grafted onto the 140 Ru rootstock, the maximum trunk girth and number of canes/vines were observed. Conversely, in the case of Manjari Kishmish, the 110 R rootstock resulted in the highest trunk girth and number of canes/vines. Additionally, the maximum leaf area was recorded in both Manjari Medika and Manjari Kishmish grape varieties. In summary, the study revealed the influence of different rootstocks on graft success and growth parameters in the studied grape varieties, with distinct rootstock-performance relationships observed for trunk girth, number of canes/vines, and leaf area.

Development of agro-techniques

Based on cropping patterns including cropping systems, intercropping and alternative crops. Relocation of crops in alternative areas *e.g.* shifting of apple belt in HP. Planting different varieties or crop species. Adjusting cropping season, modifying the planting date or date of sowing and off-seasonal production & marketing of horticultural crops. Using sustainable, customized or liquid fertilizer (Nano Fertilizer). Implementing new or improving existing irrigation systems like drip irrigation. Improvement in crop residue and weed management. Changes in land use management practices. Rain Water Conservation. Tillage practices to improve soil drainage, zero tillage, etc.

Tripathi *et al.* (2019) [20] conducted an experiment on the effect of the intercropping of medicinal and aromatic plants on the yield of peach cv. July Elberta in the experimental farm of the Department of Fruit Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh and observed that the highest fruit weight (64.98 g) was recorded in T_2 (peach + *Withania somnifera*) and lowest (61.64 g) in T_4, control. The fruit length was highest in T_2 (58.65 mm and 59.35 mm) and lowest in T4 (53.69 mm and 54.90 mm) in both years of study. Fruit diameter was maximum in T_2 (52.61 mm and 53.36 mm) and minimum (46.34 mm and 47.61 mm) in T4 in both the years of study respectively. The maximum fruit volume (68.40 cm^3 and 69.60 cm^3) was recorded in T_2 and the minimum (64.00 cm^3 and 65.20 cm^3) was recorded in T_4.

Raj *et al.* (2021) [17] examined the impact of location and varieties on the chemical composition (g 100 g−1 FW) of low-chilling apple fruits. The data revealed notable differences among the different varieties and growing locations. Dorsett Golden, grown in the eastern Himalayas, exhibited the highest moisture content (97.06), followed by Fuji from the western Himalayas (88.20), while Anna cultivated in the western Himalayas showed the lowest moisture content (77.84). In terms of protein content, Dorsett Golden from the eastern Himalayas exhibited the highest value (1.87 g 100 g-1), followed by Fuji from the western Himalayas (1.49 g 100 g-1). The lowest protein content (0.85 g 100 g-1) was observed in Anna grown in the western Himalayas. Regarding carbohydrate content, Fuji cultivated in the western Himalayas had the highest value (3.25 g 100 g-1), followed by Anna from the same location (3.18 g 100 g-1), which was comparable to Anna cultivated in the eastern Himalayas. The lowest carbohydrate content (1.69 g 100 g-1) was found in Dorsett Golden grown in the eastern Himalayas. In summary, the study highlighted significant variations in the chemical composition of low-chilling apple fruits influenced by both the variety and the growing location.

Efficient use of resources

Adopting new farm techniques, resource-conserving technologies (*e.g.* bagging of fruits, fertigation, etc.). The bagging of mango fruits at the marble stage with skirting bag and brown paper gave maximum fruit retention while bagging with newspaper bag gave the highest fruit weight and fruit bagged with newspaper and brown paper bags were free from spongy tissue.

Haldankar *et al.* (2015) [7] A study was conducted to assess the impact of fruit bagging during the marble stage on the quality of Alphonso mangoes in the Dapoli region. Maharashtra and revealed that fruit retention and weight of fruit was significantly improved by pre-harvest bagging with newspaper bag (71.25%) and (264.07 g), brown paper bag (71.67%) and (254.47 g), skirting bag (71.67%) and (243.53 g) over control respectively. Also, pre-harvest bagging with newspaper bag and brown paper bag had no incidence of spongy tissue.

Deshmukh *et al.* (2021) [5] The distribution of respondents was examined based on their familiarity with various climate-resilient mango production technologies in the coastal zone of

South Konkan, which comprises two districts: Ratnagiri and Sindhudurg and observed that using the recommended dose of paclobutrazol during July-August; providing irrigation (100-200 liter/tree) to reduce dropping of pea size fruits, Rejuvenation of old and senile orchard was also reported by the 100.00% of the mango growers using recommended spraying schedule of university for, insect-pest management, paper bagging of fruits from the ‘Marble to Egg’ stage was found effective Additionally it was also observed that majority (85.89%) of respondents were familiar with canopy management in mango crops and spraying with Gibberellic Acid (GA) 50 ppm to avoid recurrent flowering (61.54%), spraying with 1% Potassium Nitrate for increased fruit retention (51.92%). However, only 7.05% of respondents were aware of spraying Naphthalic Acetic Acid (NAA) at a concentration of 20 parts per million (ppm) to prevent fruit drop in mango.

Improved pest and disease management

Efforts are being made to develop an insect and disease forecasting system, establish a comprehensive database, and implement efficient management methods in order to enhance pest and disease control in agricultural systems. Strengthening surveillance measures for pests and diseases is also a key component of these initiatives. Furthermore, studying the patterns of escalating climatic variability and change is crucial as it can contribute to the rapid proliferation of pathogens and insect pests in agricultural environments.

Use of anti-transparent

Anti-transparent substances such as chitosan, kaolin, and liquid paraffin are known to reflect heat radiation from plant parts, resulting in reduced water loss through transpiration and decreased surface temperatures of fruits and leaves. Among these substances, the treatment of banana plants with 2% chitosan anti-transparent spray showed significant effects, leading to maximum average finger weight, average hand weight, and bunch weight compared to other treatments.

Ahmed (2014) [1] notable finding in banana cultivation was that the application of a 2% chitosan anti-transparent spray resulted in the highest average finger weight (108.0 g), average hand weight (3.15 kg), and bunch weight (25.3 kg).

Distinctive agricultural technique-Mulching

Mulching is an agricultural technique that offers multiple benefits, including the conservation of soil moisture and the improvement of soil microclimate, microbial activity, and overall soil health. By applying a layer of organic or inorganic material to the soil surface, mulching acts as a protective barrier that helps retain moisture, preventing excessive evaporation. This, in turn, ensures a more consistent water supply for plant roots, promoting optimal growth and reducing water stress. The plastic mulch increased yield percentage in papaya (64.24%), mango (45.23%), banana (33.95%), ber (27.06%), guava (25.93%), pineapple (14.63%) and litchi (12.61%) as compared to control and in strawberry maximum runner plant yield observed with the treatment of white-on-black plastic mulch at warmer location, while black plastic mulch at cooler location.

Nidhi *et al.* (2021) [12] investigated the impact of different mulching techniques on the growth and yield of Guava (*Psidium guajava* L.) at the experimental central orchard of the Department of Horticulture, Naini, Agriculture Institute, SHUATS, Prayagraj Treatment T5 black plastic gave the minimum days required for flowering (34.49), days required from flower to fruit set (29.74), days required from fruit set to maturity (132.12) the maximum number of flower per plant (192.54), number of fruit per plant (186.46), fruit weight (122.20 g), fruit yield per tree (22.79 kg), fruit polar diameter (8.59 cm) and fruit radial diameter (8.83 cm) which was followed by T_4 white plastic, T_3 sugarcane trash, T_2 paddy and T_1 grass.

In Brinjal significantly, the highest plant height (113.80) cm), No. of branches per plant (8.97), No. of fruit per plant (12.94), average fruit weight (86.26 gm), marketable fruit yield (1.10 kg/plant and 29.76 t/ha) and lowest days to 50% flowering at TP (49.30), days to first harvesting (67.96) and days to harvesting (173.20) were recorded in treatment M2-Silver Mulch (Vasava *et al.*, 2023) [22].

Weather prediction and agricultural insurance programs for farmers

In addition, the use of Geographic Information System (GIS) technology is becoming increasingly important in agriculture, including fruit crop cultivation. We can draw a climate suitability map for the distinct location of a particular fruit crop and can grow the crop according to climate suitability requirements. A need to develop mathematical models in tropical fruit trees predicts future scenarios and consequences of flooding, droughts, elevated CO_2, etc. By selecting hardier cultivars that respond to elevated CO_2 levels and stress conditions. The use of phonological scales or the landmark stage is the key factor for understanding the responses of trees to climate change.

Conclusion

Climate change has significant impacts on fruit crops, affecting various aspects of their growth and development. These impacts include disturbances in flowering patterns, reduced fruit set, increased pollination failures, hindered colour development and higher incidences of physiological disorders. Additionally, climate change leads to the shifting of suitable areas for fruit production, with certain crops experiencing inadequate chilling hours that affect dormancy breaking and overall yield, particularly in temperate fruits like apples.

Furthermore, climate change brings about changes in the distribution of pests, diseases, and weeds, as well as an increased threat of new incursions. To mitigate the negative effects of climate change on fruit crops, implementing climate resilience strategies is crucial. This includes the cultivation of climate-ready crops such as dragon fruit, phalsa, pummelo, beal, wood apple, aonla, karonda and barbarous cherry. Additionally, adopting low chilling requirement varieties like Anna in apples, using drought-tolerant varieties like Ruby in pomegranates and selecting suitable rootstocks like 110R and Dogridge in grapes are beneficial measures. Agro-techniques like fruit bagging for mangoes and pomegranates can help reduce the incidence of physiological disorders. The use of specific chemicals like chitosan, an antitranspirant, at a concentration of 2%, can increase bunch weight in bananas. Moreover, the application of the Bordeaux mixture can mitigate the negative effects of frost on grapes. The practice of mulching in fruit crops also aids in increasing yield.

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