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Impact of Climate Change on Fruit Production: Adaptation and Mitigation Strategies in Northeast Himalayan Region

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Abstract

Numerous horticulture crops, both well-known and less well-known underutilized fruit crops native to this region, are grown in abundance in the north-eastern Himalayan region. If grown to their full capacity, these crops will produce significant revenue and contribute to the local economy. There is however, a decrease in their availability even before being fully exploited due to losses resulting from many factors including climate change and related variability. The primary consequence of climate change, among many others, is the changes in the agro-ecological region that are observable in some places where there is the replacement of native fruits, many of which originated at higher elevations, with low chilling-required fruits. In the Ukhrul district of Manipur (Northeast India), the abundance of many local temperate crops of the Prunus species such as peaches, plums, cherries, pears, bird cherry (*Prunus nepalensis*) and others like walnut, wild apple (*Docynia indica*), *Pyrus pashia*, *Myrica* spp., *Rhus semialatus*, *Rubus* spp., *Eleagnus* spp., *Elaeocarpus floribundus*, *Spondias axillaris*, *etc*. are reduced and being replaced by low chilling requiring crops like kiwi, avocado, low chilling apples (Anna, Golden Dorsett, HRMN 99) and area under these crops particularly kiwi is increasing. In household gardens at higher altitudes, tropical fruits like mango, banana and guava are now thriving; in the past, the harsh winter frosts made it impossible even for the seedlings to survive. Despite employing rootstocks that are more resistant to higher temperature, kiwi is replacing the apple-growing regions in the foothills of Bomdila and Dirang in Arunachal Pradesh, since the requisite quality is not achieved.

Keywords: Agro-ecological shift, Climate change, Fruits, Low chilling

Introduction

The Northeastern Himalayan region is teeming with a diverse array of nutrient-rich and highly valued fruits, vegetables, medicinal and aromatic plants, as well as rare flowers. These natural resources have historically played a crucial role in the nation's prosperity and the region continues to present significant opportunities for resource extraction and development. In fact, these resource-rich ecosystems are the wealth of the region and the nation which needs to be harnessed and conserved at the same time. However, these genetic resources especially in the Northeast are alarmingly eroded even before being exploited due to various natural factors including environmental change and anthropogenic factors, directly and indirectly, contributing to climate change like urbanization, deforestation, pollution, socio and economic factors, *etc*. Climate factors, including rainfall, temperature, humidity and extreme weather events such as cyclones, floods, hailstorms, landslides, heat waves and cold waves, exert a significant influence on crop productivity.

Our understanding of the effects of climate change on horticultural crops is still constrained and tackling climate change-related challenges, particularly intricate for fruit crops compared to annual crops. A thorough study, forward planning and improved management are mandatory to address the difficulties of climate change and the problems

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that result from it. Tropical and subtropical crops shifting to higher elevations resulting in the replacement of temperate crops due to an increase in temperature are not uncommon nowadays.

There may be more problems with food security in the future due to the climate change altering the frequency and intensity of at least some extreme weather events. Focussing on combating global climate change by way of reduction on GHGs and adoption of green and resource-conserving eco-friendly technologies, climate change is globally more frequently discussed. Both the United Nations Framework Convention on Climate Change (UNFCC) and the Intergovernmental Panel on Climate Change (IPCC) have set a target of keeping the increase in global temperature below 2 °C by the year 2100, under the condition that strict emission reduction measures are implemented globally.

Over the past few years, the South West monsoon rainfall in the Northeastern Region (NER) has shown a gradual decrease compared to the levels observed in the 1980s and 1990s. This shift has led to a more frequent occurrence of unprecedented drought in the Northeast region when contrasted with Western India (Parida and Oinam, 2015). The probability of experiencing drought in the most recent decade (2000-2014) stands at 54% for the Northeastern Region and 27% for Western India.

Consequences and Climate Change Effect on Fruit Crops

Climate change is anticipated to bring about higher temperatures, variations in rainfall patterns, and an uptick in the frequency and intensity of extreme events such as heat waves, frost days, cold waves, prolonged droughts, floods and other related phenomena, resulting in decreased crop output in some regions while more deluges in others. Land deterioration and unusual geophysical events, decreased water availability, an elevation of the sea level and saline inundation are among the hypothesized alterations in ecological and agro-economic zones along the latitudinal and altitudinal axes. Climate change significantly affects plant processes such as vegetative growth, blooming, fruiting and fruit quality. The commercial crop output, particularly in open fields, would be adversely affected by these changes.

Shift in Agro-Ecological Zone

Substitution of new cultivars or species at higher elevations for temperate tree fruits has occurred as the winter chill requirement is reduced due to the warming effect. A shift in apple growing areas to higher elevations and replacement by tropical crops like mango is reported in Shimla. Climate change has led to a significant decrease in apple productivity in the Bajaura valley (1500-2200 m), with a reduction of 2-3% and apple has been replaced by out-of-season vegetables, pomegranate and kiwi fruit (in Kullu valley). Winter temperatures and precipitation, especially in the form of snow, play a crucial role in inducing dormancy, promoting bud break and maintaining blooming in apple trees (Jindal *et al.*, 2001), which is found to be associated with sharp decrease and delay in snowfall and increase in temperature (Rana *et al.*, 2008). Rajan (2008) predicted possible changes in mango-growing locations depending on the climate in the future, using the DOMAIN nice model. As a result, differences in the size of the crop and phases of maturity at harvest occur, leading to reduced yield and fruit quality, and consequentially a decrease in the fruit output and quality.

Reduction in Chilling Hours of Temperate Crops

Climate change has had an impact on temperate horticulture production systems in the form of unpredictable precipitation, a rise in temperature and fewer days that serve as the chilling phase. The melting of the Himalayan ice cap exerts a chilling impact that is necessary for many horticultural crops to bloom (Datta, 2013).

The poor apple production in the Kotkhai area of the Shimla district in Himachal Pradesh is a composite impact of all climatic variables, including substantial diurnal temperature changes with sporadic or poor rains, minimal or no snowfall and season shifts (Sharma *et al*., 2013). In temperate trees, unusual patterns of bud-break and development (Ameglio *et al*., 2000; Halgryn *et al*., 2001), irregular and temporally spread out flowering (Petri and Leite, 2004), negatively affecting pollination (Halgryn *et al*., 2001), abnormal growth and uneven crop development (Petri and Leite, 2004) were observed due to absence of chilling as in mild winter conditions. According to Campoy *et al.* (2012), clonal plant material of apricots successfully cultivated in various climatic circumstances had chilling requirement variances of more than 50%. This variance may be influenced by changes in temperature as well as other elements like latitude. The locations where crops like walnuts, pistachios, peaches, apricots, plums and cherries may be grown safely during the winter (> 700 chilling hours) are predicted to about entirely vanish by the end of the twenty-first century (Luedeling *et al*., 2009). There are remarkably few places with safe chilling levels and for varieties like apples, cherries and pears that require chilling for more than 1000 chilling hours, modeling results indicate that there won't be very many by the middle of the century.

Effect on Pollinator Activity and Pollinizer

Pollination efficiency of pollinating agents, such as bees (Reddy *et al*., 2012) and pollination services (Memmott *et al*., 2007; Hegland *et al*., 2009; Schweiger *et al*., 2010) will be impacted by climate change on a variety of levels. Climate change scenarios indicate a significant decline in the population of pollinating insects. Fruit set is negatively affected when either of the temperature extremes, low or high, occurs, leading to a lack of fertilization. The diminished presence of pollinators, a key factor in the natural pollination process, is a primary contributor to poor fruit setting in varieties such as Delicious apples. Although the northwest Himalayas require a minimum of 25% for excellent fruit set, less than 20% of orchards have pollinators, which are greater than 70% of the time (Gautam *et al*., 2003). Pollination can be lowered by insufficient chilling, which can lower crop yield for cross-pollinated fruits like pistachios and walnuts (Gradziel *et al*., 2007). According to the Millennium Ecosystem Assessment Report 2005, pollination is among one of the 15 major ecosystem services that under threat due to factors such as increasing population pressure, depletion of natural resource bases and global climate change (Sachs, 2008). Important species of pollinators including bees, moths and butterflies are facing sharp losses in population size, geographic range and pollination activity due to climate change (FAO, 2008). Numerous pollinators have evolved to synchronize their life cycles with plant phenological events. However, due to climate change, this synchrony may be disrupted, potentially leading to a reduction in the amount of pollination (Ricketts *et al.*, 2008).

Effect on Time to Flower and Mature

Certain phenological abnormalities, like late blossoming, extended flowering periods, and a prolonged duration between flowering and harvest in apples, can be attributed to insufficient chilling requirements during warm seasons (El Yaacoubi *et al.*, 2020). This phenomenon is expected to lead to a boost in annual irrigation requirements and a quicker fulfilment of heat unit requirements. In hot weather, apple blossoming occurs 15 days earlier. Acute moisture stress during April has led to large-scale flower drops. Dormancy breaking will occur earlier because of the impact on the specific chilling requirements of stone fruits and pome. The early and delayed flowering both will be the characteristic features in mangoes, where the presence of more hermaphrodite flowers in late-emerging panicles under the influence of climate change is correlated with higher air temperatures. Similar advancement was reported when apple and pear trees fully blossom in South African conditions (Grab and Craparo, 2011). There is still a chance of frost damage to apple blooms due to the increase in the season of winter and spring temperatures (January-March), which causes earlier flowering (Blanke and Kunz, 2011). Spring (late) frosts can harm apples and other temperate fruit. One event during the bloom period when the temperature falls a few degrees below zero is adequate to cause damage to flower buds. Light frosts lead to a reduction in fruit quality, while strong frosts put the harvest at risk (Snyder and de Melo-Abreu, 2005).

Effect on Flowering and Fruit Setting, Yield and Quality

Global warming is likely to reduce the frequency of future cold waves and frost occurrences. This decrease in cold events is likely to diminish the risk of yield loss from frost damage in Northern India across various crops and will also influence fruit quality. Elevated temperatures and moisture stress contribute to increased incidents of sunburn and cracking in apples, apricots and cherries; while heavy rainfall on the second and fourth nights of April resulted in poor fruit set. Strawberries, under certain conditions, prioritize the production of runners at the expense of fruit yield. The pattern of blossoming and bearing was altered under climatic changes and as a result, fruit production and quality of apple in India's Western Himalayas (Vedwan and Rhoades, 2001). Several factors contribute to the poor fruit setting of delicious apples, including insufficient winter chilling, a decline in the natural population of pollination agents, occurrences of spring frosts, hailstorms, gales, nutrient deficiencies, droughts and other related attributes (Gautam *et al*., 2003).

The production of apples though increased gradually, the productivity of apples fell from 10.8 to 5.8 t ha^{-1} owing to reasons related to climate variability, soil and crop management *etc*. (Awasthi *et al*., 2001). Low temperature promotes and high temperature in autumn inhibits anthocyanin synthesis in apple fruit (Saure, 1990). During a heat wave in summer, 2004, temperate horticultural crops were the worst hit in Himachal Pradesh (Prasada and Rana, 2006). A recorded loss of 50% of grape berries occurred due to browning and berry burn resulting from incidental heat shocks, with temperatures exceeding 35 °C (Kizildeniz *et al.*, 2018); while, sunburn in litchi occurs when the fruit is exposed to excessively high temperatures for an extended period or even briefly during its growth and development (Nath *et al*., 2019). The prevalence of sunburn and fruit breaking in apples has increased, primarily due to extreme temperature and moisture stress, which has led to a significant decline in fruit quality (Sakuma *et al*., 1995). Conversely, the extreme cold wave of 2002-2003 adversely affected certain regions in Jammu, Himachal Pradesh, Punjab, Haryana, Bihar, Uttar Pradesh and the North Eastern States. The yield loss in crops such as mangoes varied from 10% to 100%. Fruit quality and size were severely reduced in numerous crops. On the other hand, temperate crops, like apple, plum and cherry yielded higher quantities due to the prolonged cold conditions. Low-lying places where cold air condensed and lingered in the earth for longer sustained more damage than other areas (Samra *et al*., 2004).

Temperature stress has a major role in influencing the quality of pollen and ovules in a variety of fruits, which in turn affects fruit set and yield (Irenaeus and Mitra, 2014) and has a key role in promoting flowering of many fruit tree species in subtropical climates. Climate change can impact mango flowering in two distinct ways: early and late. A particularly cold spell during panicle growth will cause several problems for mango production. Low daytime temperatures during flowering may cause less pollinator activity, which in turn may result in poor fruit set, whereas low night-time temperatures may cause poor fruit set. Increased warmth stimulates sex changes in both female and hermaphrodite flowers, as well as rendering the stigma and stamen sterile in papayas, leading to flower drops. Low temperature during flowering can commonly affect flower retention in fruits like mango, guava, litchi and others; while, physiological disorders of fruit crops such as, spongy tissue of mango, fruit cracking of litchi, increase in the intensity of black tip of mango *etc*. will be more pronounced with increased temperature. In litchi, fruit set was reduced due to drought and increased fruit cracking (Menzel *et al*., 1995). Although pineapple can withstand droughts very well, absorption decreases quickly during droughts and warm temperatures accelerate this drop (Zhu *et al*., 1999). Fruit crops such as citrus and grapes may undergo accelerated development and mature approximately 15 days earlier as a result of temperature rise (Mitra, 2018). Increased CO_2 levels linked to global warming may have a favourable yield impact on some crops. In Northern India, the likelihood of yield losses for crops including papaya, guava and mango may diminish (Samra and Singh, 2004).

Effect on Pests and Disease Dynamics

The incidence of pests and diseases in crops is anticipated to undergo changes due to accelerated pathogen and vector growth, resulting in quicker pathogen transmission and increased vulnerability of the host. Many pests and diseases are more active when the temperature and humidity are higher. Climate and weather impact insect life cycle processes such as life span length, dispersal, diapauses, mortality, fecundity and genetic adaptation. Owing to the high temperature in spring, the increase in pest population is rapid as the reproduction rate is a factor (Patterson *et al*., 1999). The effectiveness of crop protection chemicals is impacted by variations in temperature and precipitation. Climate change, along with its direct effects on apple production, has exacerbated pest and disease outbreaks, which has increased yield losses (Gautam *et al*., 2013).

Effects of Climate Change on Fruit Crops in the North-Eastern Hill Region

It is observed that the higher chilling requiring crops like plum, peach, cherry, pear, walnut, wild apple (*Docynia indica*), *Eleagnus* spp., *Elaeocarpus floribundus*, *Pyrus pashia*, *Myrica* spp., *Rhus semialatus*, *Rubus* spp., *Spondias axillaris*, *etc*. which were available both in wild and cultivated forms in the hills of Manipur, India have declined considerably. In the Ukhrul district, earlier, tropical fruits like mango and guava were usually grown at the foothills near the paddy fields and survival of these crops at home gardens at higher elevations was not possible especially due to winter frost. However, these crops are now found growing at homes at higher elevations while the numbers of higher chilling requiring crops and other indigenous lesser-known crops are reduced. Less chilling requiring crops like kiwi, avocado and low chilling apples (Anna, Golden Dorsett, HRMN 99) is introduced in the Ukhrul district and is showing good performance and areas under these crops particularly kiwi is increasing. Similarly, in Arunachal Pradesh, a reduction in effective chilling temperature for crops like apples and subsequent shifts in cropping zones to higher elevations (Dirang and Ziro areas) has been reported. A high-chill requiring crop like apple is replaced by low-chill requiring crops like kiwi.

Experts and farmers have discovered that the Khasi mandarin growth in Northeast India is the most severely impacted by climate change. Citrus growth and production are believed to be falling due to a number of variables, with one important factor being a shift in climatic behavior (Singh and Ngachan, 2012). The farmers in Meghalaya's Ri-Bhoi district, however, noted in bananas that the recent rise in temperature had improved their crop's growth and increased output. There has also been an observation of guava and peach flowering ten to fifteen days earlier than usual due to mid-altitude temperature increases. Peach, plum and other crops that require little cooling also exhibited signs of deterioration (Ngachan, 2013).

A warm, humid climate is conducive to the growth of diseases like blasts and blight as well as other sucking pests like bugs and beetles, which reduces the amount of corms and cormels produced (Singh and Ngachan, 2012). Guava fruit fly numbers are alarmingly high due to the heat and humidity.

Adaptation and Mitigation Strategies for Climate Resilience

The objective regarding adaptation and mitigation of climate change is to improve ecosystem services, encompassing carbon sequestration and storage (in forests and other ecosystems), hydrological services and biodiversity, along with provisional services like fuel, small timber and non-timber forest products (NFTPs). Reducing soil temperature and moisture, reserving excess agriculture land and restoring soil carbon on the areas with reduced soil quality are ways to increase soil sequestration and reduce greenhouse gas emissions from agriculture. Soil management techniques include minimized tillage, application of manure, incorporation of residues, improvement of soil biodiversity, micro-aggregation and mulching that can be highly effective in storing carbon in the soil. While certain technologies, like site-specific nitrogen management and intermittent drying, can be easily adopted by farmers without additional funding, others necessitate financial incentives and legislative support (Wassmann and Pathak, 2007; Mitra, 2018).

The collection, characterization, conservation and evaluation of lesser-known under-utilized crops are of utmost importance. There is a pressing need for the further research of comprehensive cultivation practices for these wide ranges of indigenous crops. Modifying current horticultural techniques and utilizing greenhouse technology more are some effective strategies for mitigating the adverse effect of climate change while maintaining sustainable productivity. The creation of new horticultural crop cultivars that are short-lived, tolerant of high temperatures, disease- and pest-resistant and yield well under stress will be the primary strategies used to address these challenges. High-tech horticulture and prudent resource management may also be employed.

Conservation Practices

Conservation agriculture will be one of the most effective ways for long term climate resilient horticulture. Immediate attention is required for initiatives such as adopting renewable energy adoption, water conservation, forest conservation and engaging in reforestation.

Increase in Efficiency of Inputs

Developing location-specific models and protocols for soil and water conservation is imperative for the production of organic horticulture crops. Bio-mulches for moisture conservation are another option in stress situations. By improving N usage efficiency, N_2O emissions can be decreased. Water-conserving and efficient measures need to be adopted.

Crop Diversification

The ultimate winners will be farmers who modernize their methods and diversify their fields. Diversification of livestock and crop varieties is being promoted as a way to boost the productivity in the face of moisture and temperature stresses. This includes changing types of plant, cultivars, hybrids and animal breeds with fresh varieties meant for higher heat or drought tolerance. Using hardy rootstocks to withstand decreased or delayed rainfall and introducing new varieties suited to a ample variety of chilling hours are two potential strategies to reduce temperature rise in temperate zones.

It has been established that diversity in the genetic structure and content of seeds provides an efficient defense against climatic dangers, disease and pest outbreaks. It is necessary to promote the use of soil-borne disease-resistant rootstocks and crop cultivars resistant to insects and pests. Future crop and land-use planning must take potential climate change aspects into consideration. During periods of heat, drought and biotic stress, native genetic resources serve as a buffer, and additionally, the inclusion of genetic resources with bio-alternatives may reduce the vulnerability of production systems to the impacts of climate change (Ghosh, 2012). The North-eastern region has witnessed successful crop diversification with high-value horticulture crops and there is potential for further growth through the transfer of pertinent technologies.

Developing Suitable Crop Varieties

The primary objective in maintaining yield stability should be the development of newer crop varieties with enhanced production potential and resistance to various stresses such as drought, flood and salinity (Reddy, 2015). Germplasm improvement of fundamental priority crops for heat-stress tolerance through the breeding programme should be taken up. It is imperative to supply cultivars with a diverse genetic foundation to farmers. The availability of novel kinds that are resistant to heat, salinity and drought, that could aids in their adaptation process and reduce the likelihood of climatic anomalies.

Similarly, variety development is necessary to counteract the growing issues of a shorter growing season and other production-related whims. Farmers can enhance the stability of their production systems by exploring various technological options. Identifying crops that are tolerant to different abiotic stresses is crucial and strategies should be tailored based on specific requirements and geographical locations. Low-chilling peach varieties like Flordasun, Shan-e-Punjab, Pratap, *etc.* are suitable in areas where sufficient chilling is not available for high-chilling required peach varieties (Table 1). Similarly in apple, Anna, Golden Dorsett and HRMN 99 are being grown suitably in low chilling areas of different NE states.

Selection of Suitable Crops and Varieties

Choosing the best horticulture crops based on the soil, land and climate appropriateness will maximize the country's total improvement in horticultural crop production. A partial change in agricultural policy, to congregate the yearly increase rate in domestic requirements for fruits and vegetables, the best crop selection involves considering agro-climatic suitability and the appropriate levels of input consumption, including fertilizer, pesticides and irrigation water, must be carefully addressed. Perennial fruit orcharding has previously produced great returns in terms of stabilizing fragile ecosystems (mangos in the Western Ghats of Maharashtra and apples in Himachal Pradesh, for example) (Das *et al*., 2015). If correctly used with scientific horticultural techniques, the potential niche of hill and plateau areas can produce wealth and can transform unprofitable subsistence farming into commercially successful farming. The Konkan region in the Western Ghats has achieved success in the commercialization of fruits and vegetables like mango, cashew, black pepper, *etc*. shows that mountainous areas that were once devoid of economic opportunity are capable of being transformed. Improved management practices can boost productivity with little adverse impact on the environment, as shown by the apples in Himachal apple and cashew nuts in Konkan. Standardized and applied nutrition management techniques for various fruit cultivars and the mitigation of multi-nutrient deficiencies are needed.

Table 1: Some fruit crop varieties identified to be suitable/tolerant to different abiotic stresses in Northeast India

Stress type tolerated	Crop	Variety	References
Soil moisture stress	Peach	TA170	Singh and Ngachan, 2012
	Passion fruit	Kaveri	
Low chilling	Peach	Flordasun, Shane-e-Punjab, Pratap	Jha *et al*., 2015
	Apple	Anna, Golden Dorsett	Author's evidence of recent introduction and successfully produced in Ukhrul District, Manipur.
	Apple	HRMN 99	Author's evidence of recent introduction in some North-eastern states and successfully produced in Imphal, Manipur.

Use of Stress-Tolerant Rootstocks

Plants require rootstocks in order to mediate a variety of adaptive responses that enable them to respond to abiotic challenges (Mitra and Irenaeus, 2014). Rootstocks directly affect the plants' ability to overcome various abiotic stresses in fruits (Table 2). For instance, in acid

Table 2: Rootstocks reported with different characters for tolerance against various abiotic stresses

Crop	Stress	Scion-Rootstocks/ Remarks	References
Citrus	Drought	Cravo FCAV, Cravo Limeira, Rangpur Lime. Sweet orange on Cleopatra Mandarin. Valencia orange on FA rootstock (Cleopatra mandarin × *Poncirus trifoliata*).	Cantuarias-Aviles *et al*., 2012; Perez-Perez *et al*., 2008; Rodriguez-Gamir *et al*., 2010; Mitra, 2018
Mango	Cold	Carabao was found tolerant to different cold temperature conditions.	Ribeiro *et al*., 2002
	Salinity	Rootstocks such as 13/1, Sabre and Olour are suitable for use in soils up to 35 ESP (exchangeable sodium percentage), whereas Bappakai, Nakkare and Kurukkan are recommended as rootstocks with an ESP of up to 25.	Yadav and Singh, 2006; Mitra, 2018
Grapes	Drought	*V. berlandieri* × *V. rupestris* and *V. berlandieri* × *V. riparia*. '110R', '140Ru' and '1103P' are beneficial.	Ezzahouani and Williams, 1995; Kocsis *et al*., 1998; Chen, 2000; Mitra, 2018
	Flood	*V. cinerea* and 3309C were identified as being tolerant to flooding conditions.	Pongraz, 1983; Mitra, 2018
Apple	Drought	*Malus prunifolia* stands out as one of the most drought-resistant rootstocks.	Duan *et al*., 2009; Wang *et al*., 2012
	Flood	*M. hupehensis* thrives in wet habitats and exhibits highly resistant to water-logging, shade, cold, etc.	
Peach	Frost	Low reproductive buds damage due to frost in Redheaven on Myrobalan stock MY-KL-A	Nitransky, 1994
Annona	Flood	Pond apple (*Annona glabra*) in atemoya with the help of interstock "49-11" results in an extremely flood tolerant or flood-adapted scion-interstock-rootstock combination.	Nunez-Elisea *et al*., 1998
	Drought	*A. reticulata* and *A. montana*.	

soil-challenged regions like the Northeast, utilizing plants with high aluminum tolerance can be a viable alternative. Plants exhibit varying degrees of adaptability to aluminum variations, as observed within the same genus or among cultivars of the same species, such as citrus (Lin and Myhre, 1991; Mitra, 2018).

B-deficiency is common in citrus orchards and causes significant productivity loss as well as low-quality fruit (Han *et al*., 2008). The root systems of the rootstocks mostly determine how effective B-acquisition is. The primary determinant of citrus productivity is the morphology of the rootstocks, which can reveal important details about the roots' ability to absorb B and how well-adapted they are to low B availability. From a breeding perspective, the key to fixing the B-deficiency issues is to improve B-acquisition by modifying the root morphology or identifying citrus rootstock genotypes that are both B-efficient and B-inefficient based on the root-morphological features. Granulation incidences in Kinnow were recorded higher at 38.3% on Sohsarkar and markedly lower at 5.9% on Troyer citrange (Sharma and Saxena, 2004).

Rainwater Harvesting

The majority of precipitation in hilly regions is lost to runoff and very little of it is used for anything. In the Northeast, the country receives an average rainfall of 2450 mm or 42.0 Mha m of the 420 M ha m of total water. Unfortunately, it can only use 0.88 Mha m of water as of right now. The main reason for the annual loss of almost 41.0 Mha m of water is that the majority of it is hilly. The land remains essentially completely left fallow for 6-7 months following the rainy season, owing to the acute water shortage at the hilltop. In order to satisfy future water requirements and prevent drought, several techniques of water harvesting, such as the watershed method, Jalkund (micro-rainwater gathering structure for hills), roof water harvesting for life-saving irrigation, *etc*. should be employed.

Adoption, Analysing the Science and Fine Tuning of ITKs

Studies in anthropology and sociology have emphasized the value of social learning and community-based resource management in enhancing people's ability to adapt to the potential impacts of future climate change. Potential indigenous methods for managing nutrients and weeds, producing crops, protecting plants and absorbing and preserving rainwater are abundant in tribal and hill knowledge systems. Utilizing this information and improving it to meet contemporary demands is imperative. People's long-standing, traditional ecological knowledge may offer opportunities for adaptation as well as useful insights.

Adoption of Suitable Horti-based Land Use and Farming Systems

Horti-Silvi-Pastoral System and Multi-Tier Horticultural System

The horti-silvi-pastoral system holds significant promises to offer a sustainable land use model. This system aims to preserve crucial resources, particularly soil, while simultaneously ensuring a satisfactory level of production for fruits, vegetables, fuel wood, lumber, fodder and other essential items. In the Northeastern Hill region, this approach was determined to be an economically feasible and socially acceptable substitute for jhuming.

Conclusion

The impact of climate change on fruit crops is documented and visible in a number of ways. The impact on fruit crops ranges from affecting the flowering pattern, flowering time, floral numbers and fruit set, fruit retention and quality. Flowering and fruit set are also affected by reducing the numbers and activity of the pollinators which is one major threat not only to fruit production but the entire ecosystem involving the pollinators. In the Northeastern region, genetic erosion of valuable fruit germplasm has taken place even before being utilized to its potential. The evidence of agro-ecological shifts in the hills where the native temperate fruits like *Prunus* species such as peaches, plums, cherries, pears, bird cherry (*Prunus nepalensis*) and others like walnut, wild apple (*Docynia indica*), *Pyrus pashia*, *Myrica* spp., *Rhus semialatus*, *Rubus* spp., *Eleagnus* spp., *Elaeocarpus floribundu*, *Spondias axillaris*, *etc*. are decreased in favour of lower chilling requiring crops like kiwi, avocado, low chilling apples is distinct. These crops which constitute a potential wealth of the region need more attention and concerted efforts to practice suggested strategies for adaptation and mitigation, conservation practices, selection of suitable crop varieties, use of stress-tolerant rootstocks, rainwater harvesting, adoption, analysing, analysis and fine tuning of ITKs, and adoption of suitable horti-based land used system should be taken up.

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