Food and Agriculture
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Technical guide

BUILDING RESPONSIBLE
GLOBAL VALUE CHAINS
**FOR SUSTAINABLE
TROPICAL FRUITS**

Adapting to climate change in the tropical fruit industry: a technical guide for pineapple producers and exporters

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Abbreviations

ASPCC	Agriculture Strategic Plan on Climate Change of Thailand
ASOPROPIMOPLA	Association of Pineapple Producers of Monte Plata (Asociación de Productores de Piña de Monte Plata)
CCA	climate change adaptation
CIAT	International Center for Tropical Agriculture
COP21	Conference of Parties
CSA	Climate-Smart Agriculture
CNRF	National Phytosanitary Reference Center
EPE	expanded polyethylene
EWS	early warning systems
FAO	Food and Agriculture Organization of the United Nations
GHG	greenhouse gas
INECC	National Institute of Ecology and Climate Change
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
M&E	monitoring and evaluation
NAPs	National Adaptation Plans
NAP-Ag	Integrating Agriculture in National Adaptation Plans
NDCs	nationally determined contributions
TFNet	International Tropical Fruits Network
UNFCCC	United Nations Framework Convention on Climate Change

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Executive summary

Climate change induced by humans has become an observed reality, with countries around the world experiencing widespread and pervasive impacts on ecosystems, people and infrastructure as a result of increases in the frequency and intensity of extreme weather events. The agriculture sector is among the most affected by climate change, absorbing a large share of the total losses and damages caused by climate-related disasters in developing countries. Climate change is impacting global agrifood systems, making the goal of feeding the world's growing population more difficult than ever before. The tropical fruit sector is particularly at risk from the negative impacts of climate change driven by rising temperatures, extreme weather events including tropical cyclones, and associated challenges such as water stress and increased pests and diseases. This poses significant risks for the long term sustainability of production and trade of important tropical fruits, including pineapples.

Climate change adaptation can be described as the process of adjusting to actual or expected changes in climate and its effects. Actions taken now can reduce exposure and vulnerability to climate change impacts and build resilience in agricultural systems to ensure that these systems not only bounce back after climate shocks, but also transform to be better prepared to deal with future shocks and stresses. Some adaptation strategies also contribute to mitigating climate change, by cutting greenhouse gas (GHG) emissions and/or capturing and storing carbon from the atmosphere.

Climate plays a major role in deciding perennial fruit crop's distribution, phenology, fruit quality, and pest and disease incidents. Physiological and yield attributes of fruits are sensitive to changing climate. Environmental factors such as temperature, drought, salinity, flooding, carbon dioxide concentration and pathogens, have the greatest effect on fruit production, as these factors have a direct correlation with the regulatory physiological stages of fruit plants. The impact of climate change on perennial fruit crops is also likely to be more detrimental when compared to annual field crops, as the adaptation capacity of shorter duration crops is generally greater than perennials.

From a trade perspective, tropical fruits continue to be among the fastest growing agricultural commodities. Tropical fruits constitute an important source of economic growth, income, food security and nutrition for the rural sectors of many developing countries. High income growth in developing countries and increased awareness of the nutritional benefits of tropical fruits in developed countries are contributing to the fast growing consumption and global demand for tropical fruits. Globally, pineapple, avocado and mango continue to be the three most significantly traded tropical fruits in terms of their export quantities, after bananas. As the industry grows in value, already stressed natural resources will face additional pressure from climate change and plant diseases that spread faster, which threaten to reduce productivity. Adverse weather events and climate change continue to be major obstacles to production, particularly as the cultivation of tropical fruits takes place in climatically vulnerable tropical zones, where more extreme weather phenomena are expected.

Recognizing these challenges, the Responsible Fruits Project has developed this technical guide on climate change adaptation for the pineapple export industry. The project builds on more than a decade of FAO's experience working with the private sector on tropical fruits.[1] It works with businesses, farmers' organizations and cooperatives, importers and exporters (henceforth collectively referred to as "companies") and other actors in the pineapple value chain, with the aim to improve business performance by helping the industry be more resilient to shocks and more sustainable by strengthening or establishing risk-based due diligence systems. It also provides a confidential environment for peer learning on pre-competitive issues through webinars and other knowledge sharing and capacity development events.

This guide is part of a series of demand-driven products developed by the project. The topic of climate change adaptation was selected in partnership with project participants as a necessary topic to address in the context of building resilient and sustainable businesses.

The guide is also aligned with the FAO Strategy on Climate Change, which focuses on enhancing capacities to implement nationally determined contributions under the Paris Agreement,[2] supporting countries to adapt to and mitigate the effects and causes of climate change. This is achieved through research-based programmes and projects geared towards adapting smallholder production and making the livelihoods of rural populations more resilient.

The purpose of this technical guide is to:

- provide up-to-date information on recent and projected climate change effects and trends in key pineapple producing and exporting countries;
- identify climate change risks and impacts on the production and trade of pineapple;
- identify adaptation practices and recommendations that may help to address these risks, minimize negative impacts and build resilience;
- share good practices adopted by companies to address specific climate-related production risks in a sustainable manner; and
- identify gaps in information, research and technical solutions needed to strengthen the availability and adoption of adaptation practices.

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[1] This includes facilitating the World Banana Forum, the banana sector's premier multistakeholder platform, and work with over 30 leading agrifood enterprises and industry associations to apply the risk-based due diligence recommendations of the OECD-FAO Guidance for Responsible Agricultural Supply Chains.

[2] The Paris Agreement requires each party to outline and communicate their post 2020 climate actions to reduce greenhouse gas emissions and adapt to the impacts of climate change through nationally determined contributions (NDCs).

The guide is for producers and other value chain actors of pineapple who are interested in learning more about climate change in the context of their own business systems. It was developed through a consultative process with pineapple companies and producer organizations participating in the Responsible Fruits Project. Given the available timeframe to develop the guide and the global nature of the project, there are some limitations to the guide, which were discussed and agreed upon with companies and producer associations participating in a dedicated working group. These limitations include the inability to conduct the field-based, longitudinal scientific research that may be needed to answer specific questions related to climate change impacts over time on pineapple under various production conditions. On this basis, **the guide is intended to serve as a means to highlight the climate related risks and challenges that producers in certain countries are facing, and the adaptation solutions they are trialling to reduce these risks**, rather than a comprehensive scientific guide with prescriptive adaptation solutions to fit all contexts.

In terms of the structure of the guide, **Chapter 1** introduces the background and discusses the impact of climate change on global agriculture and tropical fruit production. It also explains the purpose and limitations of the guide as described earlier.

Chapter 2 explains the scope of the guide, including: The countries selected for further investigation into the impacts of climate change on pineapple production; the climate trends affecting these countries; and a brief overview of some of the countries' experiences to date in developing National Adaptation Plans for the agriculture sector.

Given the global focus of the Responsible Fruits Project on sustainable **production and trade** of pineapple, the selection of countries for further investigation was informed by their relative importance in **global production and exports**, and as such, constitute important sources of employment and export revenues in the identified countries. On this basis, five pineapple producing and exporting countries have been selected. Two major pineapple exporting countries, **Costa Rica and the Philippines**, were chosen for further investigation. In order to obtain a broader understanding of climate impacts on pineapple production in other countries and regions, **Ecuador, Thailand** and **Ghana** were also included based on available information.

A review of baseline climate trends and future projections for temperature and precipitation for the five countries selected was conducted based on data obtained from the World Bank Climate Risk Country profiles and general country-level data available on the World Bank Climate Change Knowledge Portal.

The World Bank estimates that **average temperatures in all the major pineapple producing countries included in this guide will increase** across all of the five emissions scenarios modelled under climate change.[3]

Precipitation variability (distribution, frequency and quantity during the year) and long term changes have differentiated effects on pineapple production, depending on whether water deficit or water excess is experienced at specific stages of the plant development. Unlike temperature, future precipitation patterns do not show a clear trend and vary depending on the region and producing country. However, **it is expected that wet regions will become wetter, while dry regions will become drier**.

In line with the above discussion on national level climate trends, it is important to understand how countries are planning and coordinating their efforts to address climate change through actions to reduce greenhouse gas emissions and implement adaptation plans at a national level. At an international level, the foundation for these actions stems from the Paris Agreement. Implementation of the Paris Agreement by each signatory is achieved through national climate action plans known as nationally determined contributions (NDCs), which outline the efforts to be made by each country post-2020 to reduce national GHG emissions and adapt to the impacts of climate change.

Climate change adaptation in the agriculture sectors is among the foremost priorities identified in developing countries' National Adaptation Plans (NAPs). To address the abovementioned challenges, since 2015, FAO and the United Nations Development Programme have partnered to work with countries to integrate adaptation solutions specifically for the agriculture sector (NAP-Ag programme) as part of the broader NAPs. Two of the key pineapple producing countries, the Philippines and Thailand, are included in the programme. While the plans developed do not focus on the tropical fruit sector, they warrant further consideration given that the identification of climate risk factors for agriculture, and the adaptation measures proposed are also relevant for tropical fruit production (e.g. water management, soil conservation, protection of biodiversity, agroforestry, early warning systems, etc.).

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[3] The World Bank estimated future mean temperatures until 2100 by using five possible future scenarios that consider the levels of emissions and the Shared Socioeconomic Pathways (SSPs) model. Each scenario analyses countries' emissions, mitigation efforts and development, using average temperatures between 1995 and 2014 as the reference period. The models are SSP1-1.9: Most optimistic scenario, describing a world where global CO2 emissions are cut to net zero by 2050. SSP1-2.6: Net-zero is reached after 2050 and temperatures stabilize around 1.8 °C higher by 2100. SSP2-4.5: CO2 emissions start to decrease after 2050 and do not reach net-zero by 2100. Progress toward sustainability is slow, with uneven development and income growth and temperatures rise 2.7 °C by 2100. SSP3-7.0: CO2 emissions roughly double from current levels by 2100 and temperatures rise by 3.6 °C by 2100. SSP5-8.5: Current CO2 emissions levels almost double by 2050. The global economy grows quickly relying on fossil fuels and leading energy-intensive lifestyles; the average global temperature is 4.4 °C higher.

In the context of the tropical fruit industry, understanding how specific commodity sectors like pineapple production and export can contribute towards the achievement of adaptation and mitigation targets set out in the NDCs and NAPs is useful. It may help the industry to align their efforts with those at a national and sub-regional level where they exist and demonstrate to policy makers that collective efforts are being made by industry to support these plans.

In **Chapter 3** we zoom in on the specific climate risks facing pineapple production across a range of countries and discuss the impact of these risks on production. Twelve important climate risks were identified through a review of the scientific literature and consultations held with producers and associations from the pineapple industry. These risks are categorized according to temperature risks (i.e. increasing temperatures, frost and low temperatures, extreme heat and solar radiation); precipitation risks (intense rainfall, changes in rainfall patterns, water shortages and drought); and mixed or "other" risks linked to climate change effects including precocious flowering, spread of pests and diseases, soil erosion and strong winds. For each of the risk factors identified, a description is given of the effects on pineapple production and impacts on social or economic dimensions of production; as well as highlighting some of the specific risks experienced in different pineapple producing countries. Understanding these risks can help pineapple producers plan to manage them.

Chapter 4 presents the climate change adaptation strategies identified in response to the risks discussed in Chapter 3 for pineapple production. These practices were identified through consultations with key stakeholders from the industry and in the scientific literature. A total of 12 adaptation practices were identified as follows: agroforestry, artificial flower induction, crop rotation, drainage systems, early warning systems, integrated pest management, integrated water management, intercropping, mulching and cover crops, solar protectors, waste management, and wind breaks and living fences. The selected practices can help pineapple producers adapt to the main climate risks identified, with direct contributions to building climate resilience. A brief description of each practice is given along with the potential for co-benefits on environmental, economic or social dimensions. Examples are also given of adaptation practices in action by companies and producer associations.

Finally, **Chapter 5** summarizes the main findings from the guide and discusses some of the challenges in designing and implementing adaptation recommendations. Gaps in information, research, technical solutions and capacity are discussed and recommendations put forward on how these could be addressed to strengthen the availability and adoption of adaptation practices.

Key messages highlighted in the chapter include:

- **Adaptation to climate change is required to ensure the continuity of global pineapple production and trade.** Adapting to climate change will enable companies and producer associations to protect their production systems and care for their environment and workers, while minimizing the creation of new risks associated with increasing GHG emissions and global warming. As such, adaptation will increase the sector's resilience to climate-related shocks.

- **It is clear that extreme weather events will increase in frequency and intensity.** Moreover, it is expected that **multiple climate risk factors will occur concurrently** in the same regions, which in combination with other non-climatic factors, such as economic slowdowns or pandemics, will increase overall risk to agricultural production systems. Pineapple producers need to be prepared to **deal with multiple risks in a synchronized manner**, which can be achieved by combining adaptation practices.
- **Knowledge and information on how to adapt to climate change in the pineapple sectors already exist**, and many companies and producer associations are taking a proactive role in designing strategies and testing practices in the field to deal with climate change and extreme weather events.
- The selected **adaptation practices highlighted in the guide address multiple climate risks and associated impacts simultaneously**. This is important, as discrete adaptation strategies that deal with only one risk factor at a time will not achieve the desired impact.
- **Climate adaptation is a continuous process that takes time and requires information and data.**
- **Adaptation and mitigation efforts to reduce greenhouse gas emissions should go hand-in-hand** whenever possible. Adopting adaptation practices that have climate mitigation potential will help to not only slow down emissions but may also extend the shelf-life of available adaptation practices. Likewise, mitigation strategies can be designed in a way to contribute to and reinforce adaptation. Some of the adaptation practices identified for pineapple production, such as sustainable soil management, agroforestry, and waste reduction and management, also have positive effects on reducing greenhouse gas emissions in the production sector.
- **All adaptation practices should aim to contribute to the three dimensions of sustainability.** While the environmental dimension is the clear entry point to promote adaptation in the tropical fruit sector, addressing social (e.g. health of workers) and economic risks (e.g. increased costs of inputs) associated with climate change impacts is also crucial to the long term sustainability of business operations.
- **Further research is needed on climate risks to human health.** Some pineapple producing companies have already noted these risks, especially those related to heat stress and associated illnesses derived from increasing temperatures and exposure to solar radiation.
- **Women and youth are among the highest risk groups when it comes to climate change impacts, yet limited information is available** on specific risk factors and adaptation solutions tailored to meet their needs. No research could be found on specific impacts of climate change on women and youth vis-à-vis engagement in global pineapple value chains. This indicates a clear gap in knowledge for the industry, given the important role women play in the harvesting and packing of pineapple. Gender-disaggregated research is urgently required to better understand the key factors that account for the differences between women's and men's vulnerability to climate change risks, and how to build tailored adaptation strategies to address them.

- Climate change has **implications for food security and nutrition**. Pineapples form part of a healthy diet and represent an important source of vitamins and nutrients for consumers in both the producing and importing countries. On this basis, pineapple companies could consider how they may support vulnerable populations in their local communities through targeted social outreach programmes that aim to improve food security and nutrition such as public procurement (e.g. school feeding programmes, community canteen services) and food banks.
- **Changes in weather patterns impact livelihoods and revenues of industry actors.** Both production and trade may be affected as production becomes more erratic under climate change conditions and quality is affected by heavy storms, peaks in temperatures more frequent pathogens and other changes. Inconsistency of supply of export-quality product can challenge the revenues generated by the sector which has flow-on effects in the upstream segments of the value chain. Unreliable production can also affect the livelihood options for producers and communities and create associated challenges for sustaining healthy and nutritious diets.
- **Enhancing the adaptive capacity and climate resilience of pineapple value chains cannot be achieved through a single-actor approach.** The complex challenges associated with climate change impacts are best solved through the cooperation of stakeholder groups including governments, companies, producer organizations, research and training institutes, worker unions, and other civil society organizations. Establishing mechanisms for multistakeholder collaboration would be the most effective approach to tackle the impacts of global warming on the pineapple industry in the future.
- **At an institutional and policy level**, FAO's work to support countries to **integrate adaptation solutions specifically for the agriculture sector as part of the broader National Adaptation Plans is an essential step**. An understanding of these plans by pineapple producers and exporters would help the industry actors to align their strategies with those at the national and sub-regional level and demonstrate to policy makers that collective efforts are being made by industry in support of these plans. Efforts to generate evidence of the impacts of implementing adaptation practices through better monitoring and evaluation are also needed to further advance these claims.

In terms of outreach beyond the guide, the Responsible Fruits project is committed to supporting pineapple producers and exporters globally to deal with climate change and other identified sustainability risks through the generation of practical tools. The project is developing various technical materials and tools tailored to the pineapple industry, with some also applicable to the wider tropical fruit sector. These products are discussed in **Chapter 5**. Two tools complement the technical guide on climate change adaptation:

- The gap analysis guide helps companies to compare the sustainability standards and policies they use with the OECD-FAO Guidance for Responsible Agricultural Supply Chains, which is the global benchmark for due diligence and responsible business conduct in the agriculture sector.

- The project is developing a **carbon and water footprint measurement tool for the pineapple industry**. The tool aims to support producers, companies and associations to better understand how they can reduce their carbon emissions and prevent the degradation of water resources through their operations, whether small, medium or large. The tool will be available for use on the project's website in the last quarter of 2023.

In conclusion, this guide was produced by the Responsible Fruits Project for producers and exporters of pineapple who are interested in learning more about climate change and how to adapt to it in the context of their own business systems. It is hoped that the guide will be the starting point for discussion on national, regional and localized climate change impacts on pineapple production and stimulate joint planning for research on adaptation solutions to support the long term sustainability of the export industry. Indeed, more longitudinal research that is commodity and location-specific is needed to better understand climate risks and long term effects on tropical fruit crops to identify innovative adaptation solutions.

Annex 1 provides a list of additional resources (project websites, publications, etc.) for those who are interested in learning more about climate change and its impacts on agriculture, tropical fruit and adaptation options.

Chapter 1.

Introduction to the guide

1.1 Global significance of climate change and its impact on agriculture: Why is adaptation needed?

Climate change induced by humans has become an observed reality, with countries around the world experiencing widespread and pervasive impacts on ecosystems, people and infrastructure as a result of increases in the frequency and intensity of climate and extreme weather events. These events include hot extremes on land and in the ocean, heavy precipitation, drought, fires and tropical cyclones that are expected to affect all regions of the world now and in coming decades (IPCC, 2021, 2022). The agriculture sectors are among the most affected by climate change, absorbing a large share of the total losses and damages caused by climate hazards in developing countries (FAO, 2018a). Global warming is impacting global food production systems, making the challenge of feeding the world's growing population more difficult than ever before. Although global agricultural productivity has increased, climate change has slowed this growth over the past 50 years (IPCC, 2022). Increasing weather and climate extreme events have exposed millions of people to acute food insecurity and reduced water security, with the largest impacts observed in many locations in Africa, Asia, Central and South America, Small Island Developing States and the Arctic (IPCC, 2022).

In addition, the link between climate change impacts and biodiversity loss is clear. Loss of species, and degradation and damage to ecosystems have been observed in every region due to past global warming (IPCC, 2021, 2022; FAO, 2016). Destruction of natural habitats, deforestation and exposure to synthetic chemicals have all contributed to the loss of beneficial organisms such as pollinators and pest-control regulators, affecting crop production (FAO, 2021b). These risks will continue to escalate with each increment of global warming and have a significant impact on the availability of nutritious food (IPCC, 2022; FAO, 2021b). Loss of genetic diversity also reduces the availability of genetic variation to breed crops to withstand climate change and the biotic stresses stimulated by it and reduces the range of crops and livestock available to provide a healthy diet (FAO, 2021b).

From a global perspective, a summary of observed impacts of climate change on agriculture include (IPCC, 2022):

- overall negative impacts on agricultural productivity with regional differences;
- drought-related crop loss has increased in recent years and has affected about 75 percent of the global harvested area;
- reduced food and water security, especially for vulnerable groups;
- increases in frequency and intensity of droughts, floods and heatwaves;
- diminished water availability;
- increased pressure from pests and diseases;
- loss of biodiversity and ecosystem services (including pollination); and
- future risks will continue to increase in near, mid and long term (2100).

From a social perspective, the impacts of climate change on agriculture disproportionately affect vulnerable rural communities who rely heavily on agriculture for their livelihoods. Women and youth are among the most affected due to their limited access to resources and services; reduced voice in decision-making regarding natural resource management and environmental services; lower endowments and entitlements to land; and limited mobility options to pursue livelihood opportunities elsewhere (FAO 2016, 2018a, 2019b, 2022c). This negatively impacts the daily lives of families by increasing the risk of poverty, food insecurity and malnutrition particularly for women and girls (FAO, 2022b). Action is urgently needed to redress the power balance by proactively targeting the inclusion of vulnerable persons in the development of national climate change adaptation plans to reflect their wants and needs. At the same time, investment is also needed to build the capacity of these populations to adapt to climate related shocks (FAO, 2018a, 2019b, 2021b). The tropical fruit sector is particularly at risk of the negative impacts of climate change driven by rising temperatures, extreme weather events including tropical cyclones, and associated challenges such as water stress and increased pests and diseases. This poses significant risks for the long term sustainability of production and trade of important tropical fruits including pineapples.

Climate change adaptation can be described as the process of adjusting to actual or expected changes in climate and its effects. An urgent call to action was made in the latest Intergovernmental Panel on Climate Change (IPCC) report (2022), which found progress on adaptation uneven across countries, with increasing gaps between action taken and what is needed to deal with the growing climate risk, particularly in lower income countries. Actions taken now can reduce exposure and vulnerability to climate change impacts and build resilience in agricultural systems to ensure that these systems not only bounce back after climate shocks, but also transform to be better prepared to deal with future shocks and stresses.

The agriculture sector also plays a crucial role in climate change mitigation. While it is estimated that agri-food systems contributed to 31 percent of greenhouse gas (GHG) emissions in 2020, the sector also holds some of the most important solutions to meet local and global climate goals (FAO, 2022f). Actions to restore and protect forests and other ecosystems, preserve soils and water resources, minimize agrochemical use, reduce food losses, among others, can promote adaptation, while reducing GHG emissions and storing carbon (FAO, 2016).

1.2 Climate change and its impact on global tropical fruit production and trade

Climate plays a major role in determining perennial fruit crop distribution, phenology, fruit quality, pest and disease incidents (Bhattacharjee *et al.*, 2022). Physiological and yield attributes of fruits are sensitive to changing global climate and reproductive stages of perennial fruits are the most susceptible to climate change, with implications on the quantity and quality of fruits produced. Environmental factors, such as temperature, drought, salinity, flooding, rise in carbon dioxide concentration and outbreaks of insect pests, have the greatest effect on fruit production, as these factors have a direct correlation with the regulatory physiological stages of fruit trees (Nath *et al.*, 2019; Sthapit, Ramanatha and Sthapit, 2012). Although perennial fruits have a number of survival mechanisms that allow them to cope with environmental stresses, these come at considerable energy cost, potentially reducing fruit productivity.

The impact of climate change on perennial crops is also likely to be more detrimental when compared to annual field crops, as the adaptation capacity of shorter duration crops is generally greater than that of perennials (Chawla *et al.*, 2021). In comparison to annuals, developing a new fruit tree variety may take 15 to 20 years, making it more difficult to compete with the challenges brought about by climate change (Bhattacharjee *et al.*, 2022). Some of the common effects of climate change on the phenology of fruit crops are highlighted in **Table 1**. It should be noted however, that the impacts of climate change are highly dependent on both the fruit crop analysed and the agroclimatic conditions in a particular location. For example, a crop like banana might become less suitable under increased temperature and changed rainfall conditions, but others such as coconut and mangoes might become more productive (Mitra, 2016). For this reason, more longitudinal research that is commodity and location specific is needed to better understand climate risks and effects on tropical fruit crops, adaptation options and opportunities for production in new locations (Sthapit, Ramanatha and Sthapit, 2012).

Table 1. Impacts of climate change on the phenology of fruit crops

Climate change effects	Impacts on fruit crops
High temperature & increased solar radiation	• Increased evapotranspiration and irrigation requirements; potential for increased soil salinity; • affects flowering: early or delayed flowering, poor fruit set, reproductive buds transform into vegetative buds, changes in the timing of fruit maturity; • disruption of pollinator populations and pollination activity; • sunburn damage to fruit and branches, and fruit cracking; • increase in soil temperature can accelerate decomposition of soil organic material, resulting in depletion of soil fertility; • production shift to new areas/changing industry location; and • incidence of new pests and diseases.
Lower precipitation	• Stress prior to or during the flowering and post-blooming periods in perennial fruit plants has a negative impact on yields through lower numbers of fruits and cell reduction of remaining fruit; • fruit and flower drop; and • supplementary irrigation requirements in rainfed agriculture.
Increased precipitation and humidity	• Excessive vegetative growth and flower drop, • waterlogged soils kill off beneficial soil microorganisms increasing disease risk from fungal pathogens (e.g. Pythium and *Fusarium*) and reducing water and nutrient uptake; • increase in pests and diseases with faster reproductive cycles; • new pests/minor pests becoming major pests; • increased risks of soil erosion by water runoff in production areas; • plant and fruit losses; and • risk of nutrient runoff pollution of water bodies.
Lower temperature & lower solar radiation	• Can affect flowering, reducing pollination, fruit set, fruit retention and size; and • frosts affect flower buds and flowers, reducing fruit size.
Other extreme climatic events (cyclones, hailstorms, etc.)	• Fruit and flower loss; • tree/plant damage; and • infrastructure damage.
Increased CO_2	• Positive effects of rising CO_2 in plants include reduced stomatal transpiration and increased water use efficiency, higher photosynthetic rates and augmented light use efficiency, leading to greater potential for fruit set and fruit retention. • Rise in temperature and a shift in rainfall pattern may cancel out the positive effects and increasing requirements for water and nutrients (nitrogen fertilizer) may be needed under increased CO_2 growing conditions.

Source: Authors' own elaboration with content adapted from Bhattacharjee *et al*. (2022); Chawla *et al*. (2021); Nath *et al*. (2019); Mitra (2018); Fischer *et al*. (2016) and Sthapit, Ramanatha and Sthapit (2012).

From a trade perspective, tropical fruits continue to be among the fastest growing agricultural commodities. These fruits constitute an important source of economic growth, income, food security and nutrition for the rural sectors of many developing countries. Their importance in global food supply has increased significantly in recent decades. This has been confirmed by the fast expansion in global trade flows, which reached a total of 20.5 million tonnes for bananas in 2021, and 8.4 million tonnes for the four major tropical fruits – mango, pineapple, avocado and papaya – combined (UN Comtrade, 2023). World trade in major tropical fruits expanded by 6.8 percent in 2021, reaching a record volume of USD 10.4 billion in 2014–2016 constant terms (FAO, 2022d). High income growth in developing countries and increased awareness of the nutritional benefits of tropical fruits in developed countries, are contributing to fast growing consumption and positive global demand for bananas and tropical fruits (Altendorf, 2019 in FAO, 2019).

As the industry grows in value, already stressed natural resources will face additional pressure from climate change and faster spreading plant diseases, which threaten to reduce productivity (Liu, 2017). Adverse weather events are major obstacles to production, particularly since the cultivation of tropical fruits takes place in climatically vulnerable tropical zones where more extreme weather phenomena are expected (IPCC, 2022). The effects of global warming are resulting in a higher occurrence of droughts, floods, hurricanes and other natural hazards, which increase the risk of producing tropical fruits. From a commercial perspective, this makes it more difficult to predict marketable surplus year-on-year, and more costly given the perishable nature of tropical fruits, the inputs required and infrastructure needed to supply international markets. This challenge cuts across the export industry since the majority of tropical fruits are produced in remote, informal settings, where cultivation is highly dependent on rainfall, prone to the adverse effects of increasingly erratic weather events and in many cases disconnected from major transport routes (FAO, 2022e).

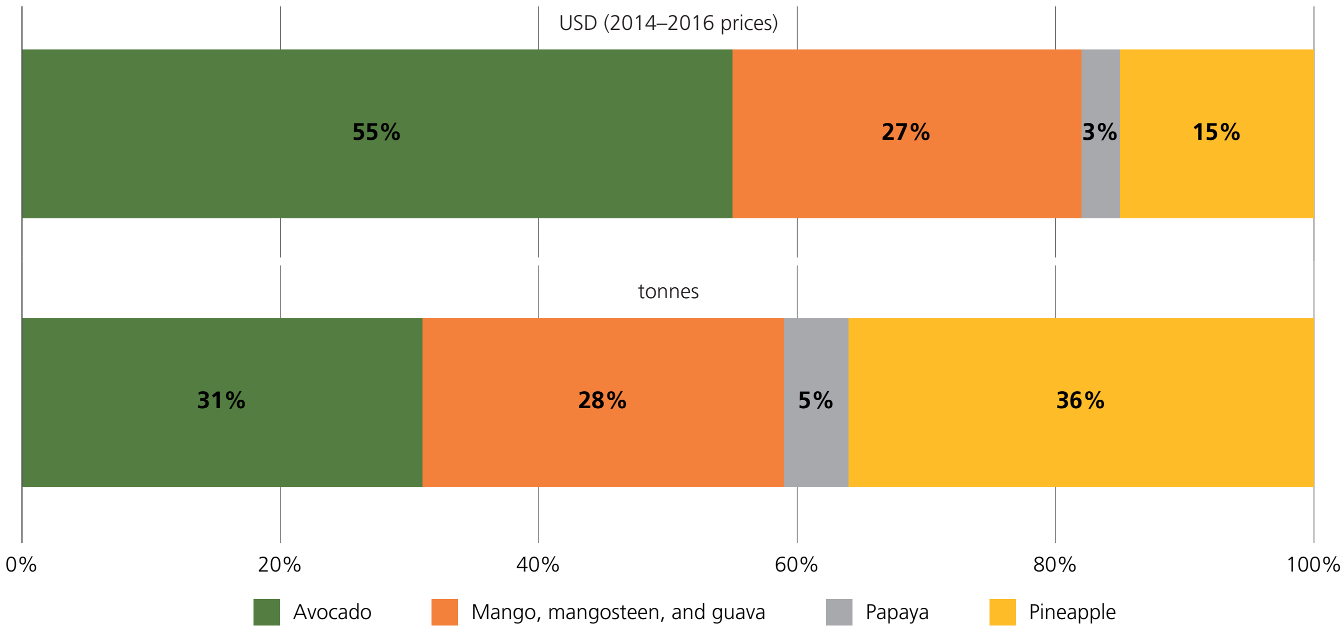
The leading exporters of major tropical fruits including pineapple are concentrated in Latin America and the Caribbean (FAO, 2019b, 2022d). Large volumes of tropical fruits are shipped from the region, predominantly to the United States of America and the European Union, the biggest importing regions globally. However, the availability of product for export is highly dependent on seasonal climatic conditions in producing countries. In the future, consumers in developed countries may suffer as a result of an over-reliance on climate vulnerable countries for their supplies of fresh fruit and vegetables. This may have potentially negative consequences for the availability, price and consumption of fruit and vegetables in countries such as the United Kingdom, where an estimated 70 percent of fruits available for purchase are imported from outside of the European Union (Frankowska, Jeswani and Azapagic, 2019). Thus, disruptions to the supply of fruits due to climatic effects in producing countries has the potential to affect the dietary intake and health of consumers in importing markets, particularly of older people and low-income households (Scheelbeek *et al*., 2020).

In addition, countries which have typically exported tropical fruits in the past, and who rely on these exports for foreign income and employment creation, many now face new competitors for import markets due to global warming. Countries that had a temperate climate could become increasingly capable of producing such fruits. As a result, current tropical fruit producers may need to explore possibilities of expanding their domestic and regional markets to reduce the risks associated with increasing competition for international markets from non-traditional producer countries (Liu, 2017). Likewise, current producers may be motivated to defy their production possibility frontier by expanding into new production areas or shift production locations to find more suitable agroclimatic conditions to ensure they continue meeting market demands. Such practices can also exacerbate climate risks by degrading vital natural resources (soil, water and forests) and ecosystems. **More specifically, what does this mean for production and export of pineapples?**

1.3 Pineapples as important tropical fruit exports at risk of climate change impacts

Global demand for the major tropical fruits remains strong despite significant bottlenecks in global supply chains and rising input and transport costs. Pineapple, avocado and mango continue to be the three most significantly traded tropical fruits in terms of their export quantities, bananas aside. In 2021, global exports of pineapples reached approximately 3.2 million tonnes, up 5.7 percent on export figures for the previous year (FAO, 2022e). Pineapple remains the most popular of the four tropical fruits in terms of quantities exported, primarily driven by the fruit's extremely low average export unit values (**Figure 1**).

Figure 1. Major tropical fruits: Share of 2022 (preliminary) export quantities by type, measured in USD billion, constant dollar (2014–2016) and tonnes



Source: **FAO.** 2023a. *Major Tropical Fruits Market Review. Preliminary results 2022*. Rome.

Against this background of strong international demand for pineapples, in **Chapter 2** we discuss climate trends facing the major pineapple producing and exporting countries around the world. Predicted climate effects over the coming decades suggest that production is likely to become more challenging in the future, particularly if adaptation and mitigation measures are not urgently adopted within the coming years. Many countries are already seeing the negative impacts of climate change and extreme weather events on production. For example, tropical hurricanes have impacted on pineapple exports from the Philippines, while the El Niño and La Niña climatic cycles cause disruption in supply from Costa Rica, with excessive rainfall and tropical storms reducing shipments from the country by 6.1 percent in 2019 compared to 2018 figures (FAO, 2020).

Preliminary results for 2022 suggest that the volume of world trade in major tropical fruits looks likely to fall to USD 9.9 billion in constant 2014–2016 dollar terms, marking a decline of 5 percent from 2021 (FAO, 2023a). This would constitute the first significant contraction of trade in the global market for tropical fruits. Preliminary data indicate that shortages in global supplies associated with adverse weather, persisting bottlenecks in global supply chains as well as high input and transport costs have contributed to the decline. For pineapples, adverse weather conditions, in particular cooler than normal temperatures, resulted in production declines from several major tropical fruit production zones, most notably a drop in pineapple supplies from Costa Rica (FAO, 2023a). Building the sustainability and resilience of tropical fruit value chains to environmental, economic and social shocks has never been more important to ensure production and trade of these important commodities.

1.4 The Responsible Fruits Project and the FAO Strategy on Climate Change

The development of this technical guide is an output of the Responsible Fruits Project. In 2019, the Markets and Trade Division of the United Nations Food and Agriculture Organization embarked on a global project titled "Building responsible global value chains for the sustainable production and trade of tropical fruits" (also known as the "Responsible Fruits Project"). The project works with businesses, farmer organizations and other actors in the pineapple value chain, with the aim to improve business performance by helping this value chain be more sustainable and more resilient. The project builds on more than a decade of FAO experience working with the private sector on tropical fruits.[4] The outcome of this project will be a network of companies committed to improving their resilience and the environmental, social and economic impacts of their operations and those of their suppliers.

The project aims to help companies operating in pineapple supply chain to strengthen or establish risk-based due diligence systems that will make their operations more sustainable and resilient to shocks.

[4] This includes facilitating the World Banana Forum, the banana sector premier multistakeholder platform, and work with over 30 leading agrifood enterprises and industry associations to apply the risk-based due diligence recommendations of the OECD-FAO Guidance for Responsible Agricultural Supply Chains.

It also provides a confidential environment for peer learning on pre-competitive issues through peer learning webinars and other knowledge sharing and capacity development events. This guide is part of a series of demand-driven guides[5] to be developed by the project on specific technical challenges determined by project participants.

A baseline survey conducted by the project in 2021 highlighted climate change impacts as one of the most important challenges facing pineapple companies (together with economic constraints and lack of access to new technology and innovation). This finding was further confirmed in 2022, when the project conducted an online survey on resilience and asked pineapple companies to identify the main issues increasing the susceptibility of their operations to suffer from external shocks. Pineapple value chain actors considered environmental and climatic factors as the main drivers of vulnerability in their businesses (100 percent of actors surveyed). On this basis, the topic of climate change adaptation was selected in partnership with project participants as a suitable topic for this technical guide.

This guide is aligned with the FAO Strategy on Climate Change (FAO, 2022c), which focuses on enhancing capacities to implement nationally determined contributions the Paris Agreement.[6] The Strategy supports countries to adapt to and mitigate the effects of climate change through research-based programmes and projects geared towards adapting smallholder production and making the livelihoods of rural populations more resilient. The Strategy moves away from a reactive response to crises to proactively preventing and anticipating them, supporting people before, during and after shocks. The Strategy focuses on a) giving a leading voice to farmers and other agriculture-dependent communities in the development of adaptation strategies, b) fostering horizontal and vertical integration and c) promoting transformative change. By implementing this Strategy, FAO aims to support member countries in their efforts to implement climate change adaptation and mitigation practices, while working towards climate-resilient and low-emission agrifood systems that strive to achieve the Sustainable Development Goals, in particular eradicating hunger and malnutrition. As noted earlier, tropical fruits play an important part in a healthy diet. This guide aims to contribute towards this Strategy by proactively increasing the awareness of producers and exporters of pineapples to climate related risks and sharing adaptation strategies as described below.

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5 The first technical guide titled "Gap analysis to support due diligence in the avocado and pineapple sectors is available here.

6 The Paris Agreement requires each Party to outline and communicate their post 2020 climate actions to reduce greenhouse gas emissions and adapt to the impacts of climate change through nationally determined contributions (NDCs).

1.5 Purpose of the guide and who is it for?

The purpose of this technical guide is to:

- provide up-to-date information on recent and predicted climate change effects and trends in key pineapple producing and exporting countries;
- identify climate change risks and impacts on the production and trade of pineapple;
- identify adaptation practices and recommendations that may help to address these risks, minimise negative impacts and build resilience;
- share good practices adopted by companies to address specific climate-related production risks in a sustainable manner; and
- identify gaps in information, research and technical solutions needed to strengthen the availability and adoption of adaptation practices.

The guide is for producers and exporters of pineapple who are interested in learning more about climate change in the context of their own business systems. It is anticipated that for many producers and exporters, this guide may be a starting point for stimulating discussion and future research on national and region-specific climate change impacts on pineapple production, and joint planning on adaptation solutions to support the long term sustainability of the export industry. Although the guide is focused on adaptation, it should be noted that adaptation and mitigation efforts to reduce GHG emissions go hand-in-hand, and mitigation strategies can also be designed in a way to contribute to and reinforce adaptation. For example, strategies to enrich carbon content in agricultural soils have the potential to deliver strong mitigation outcomes, while at the same time soils that manage to build organic carbon by minimizing tillage, erosion and chemical use also improve crop production and profitability (Scherr and Sthapit, 2009 in Bioversity, 2014).

The practices selected are also aligned with FAO's work on sustainability, by promoting techniques, technologies and actions that enable transformation of value chains towards green and climate resilient practices. These include agroecology, climate-smart agriculture, conservation and digital agriculture.

1.6 Methodology and limitations of the guide

This guide was developed through a consultative process with pineapple companies participating in the Responsible Fruits Project. In June 2022, the project held a webinar to introduce the topic and discuss what climate change means to pineapple companies. Pineapple companies shared their experiences of recent impacts of climate change on production systems during a panel session, followed by a lively discussion session. The purpose of the guide was introduced and agreed upon, and participants were invited to register their interest to join a working group on climate change adaptation to develop the guide.

Four online working group sessions were held in support of the guide:

- Working group 1 Session on 13 Oct 2022 with participants in Latin America to identify climate risks and impacts on production.
- Working group 2 Session on 24 November 2022 with participants in Asia in partnership with the International Tropical Fruit Network (TFNet) to identify climate risks and adaptation practices for pineapple production.
- Working group 3 Session on 30 November 2022 with participants in Latin America to identify and discuss adaptation practices.
- Working group 4 Session on 13 April 2023 to present the draft guide and validate the draft chapters 4 on adaptation practices with all participants involved in the Responsible Fruits Project.

In addition to the inputs from the working group members, the drafting of the guide has been supported by key informant interviews with individual companies, research institutions and with climate change focal points from FAO Country Offices in regions and countries where pineapple production and export are important. These interviews helped to develop the company adaptation practice examples given in **Chapter 4**, and to determine relevant projects and research outputs produced by FAO Country Offices or their research partners. An extensive review of the literature was also conducted covering FAO publications on climate change, reports from international agencies working on climate change (e.g. IPCC, World Bank, OECD, CIAT), scientific journals on agronomic practices and impacts of climate change on tropical fruit production in general, and pineapple production specifically.

What the guide is and is not: some limitations

During the working group sessions, the limitations of the guide were discussed with participants. Given the timeframe to develop the guide and the global nature of the Responsible Fruits Project, it was not possible to conduct the field-based, longitudinal scientific research that may be needed to answer specific questions related to climate change impacts over time on pineapples under various production conditions. On this basis, the guide is not intended to be a comprehensive scientific guide with prescriptive adaptation solutions to fit all contexts. Rather, it aims to highlight the climate related risks and challenges producers in certain countries are facing, and the adaptation solutions they are trialling to minimize future risks. Additional review of the scientific literature has been conducted to further validate the adaptation practices identified by companies. The guide also recognizes that adaptation efforts require the collaboration among different state and non-state actors to be sustainable in the long term.

1.7 Structure of the guide

Chapter 1 introduces the background to the guide and discusses the impact of climate change on global agriculture and tropical fruit production. It also explains the purpose and limitations of the guide.

Chapter 2 explains the scope of the guide, including the countries selected for further investigation into the impacts of climate change on pineapple production; the climate trends affecting these countries; and a brief overview of some of their experiences to date in developing National Adaptation Plans for the agriculture sector.

Chapter 3 introduces the climate risks facing pineapple production across a range of countries and discusses the impact of these risks on production.

Chapter 4 presents and discusses climate change adaptation strategies for pineapple production.

Chapter 5 discusses some of the challenges in identifying climate risks and adaptation solutions, and identifies gaps in information, research and technical solutions that need to be addressed to strengthen the availability and adoption of adaptation practices.

Annex 1 provides a list of additional resources that may be of use to those companies who are interested in learning more about climate change and its impacts on agriculture, tropical fruit and adaptation options.

Chapter 2.

Scope of the guide

As discussed in **Chapter 1**, climate change is affecting countries and regions differently, and therefore, for a guide on adaptation to be meaningful, some further investigation into country-specific climate trends and national adaptation strategies is required. Given the global focus of the Responsible Fruits project on **sustainable production and trade** of pineapple, the selection of countries for further investigation in this guide has been guided by their relative importance in **global production and export** as an important source of foreign income and employment. On this basis, five pineapple producing and exporting countries have been selected for deeper analysis as discussed below.

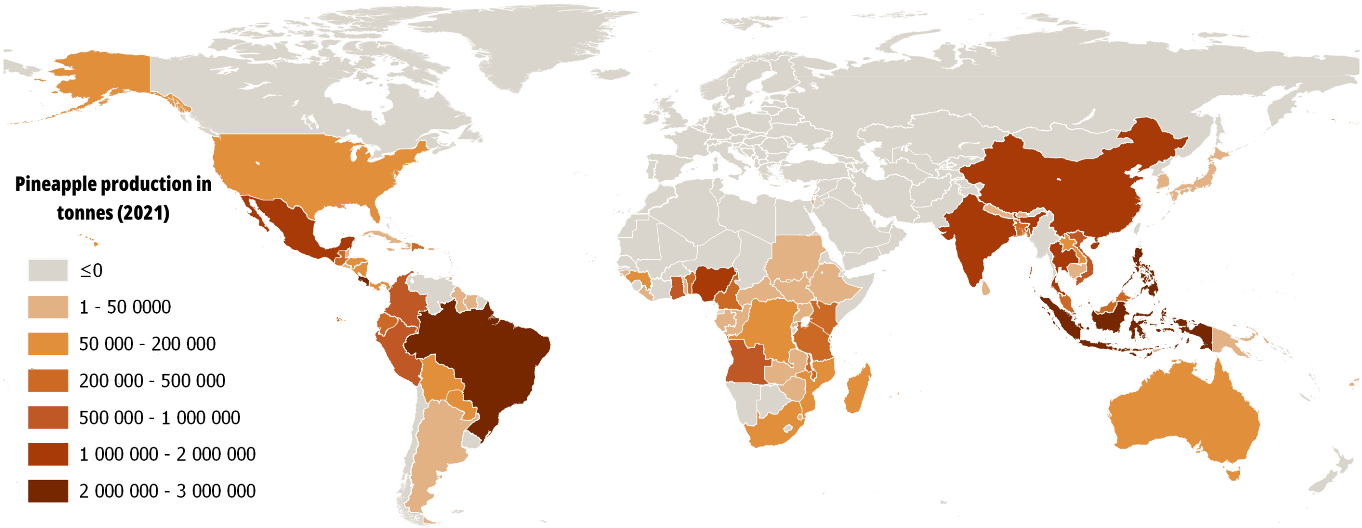
It should be noted that production of pineapple in other major producing countries that were not selected, such as Brazil, will also be affected by climate change in the future. This may result in reduced availability of the fruit for domestic consumers as the major outlet for their production, or excess supply depending on the fluctuations of climatic conditions from year-to-year. Therefore, the guide may also be of interest to producers in those countries that are facing similar climatic threats regardless of their engagement in the export sector.

2.1 Pineapple production and export

2.1.1 Global production of pineapple

According to FAOSTAT, pineapple production is recorded in more than 80 countries worldwide, with growth from 15.8 million tonnes in 2002 to 28.6 million tonnes in 2021. As seen in **Figure 2**, the Asian region produces the largest share of pineapple globally, accounting for approximately 46 percent of production in 2021, followed by the Latin American and the Caribbean region accounting for 35 percent. Within these regions, the production of pineapple is dominated by specific countries, with Costa Rica, Indonesia and the Philippines each accounting for a share of approximately 10 percent of global production (FAO, 2023b). Other major producers servicing their domestic markets include Brazil and China, accounting for 8 percent and 6.6 percent of global production respectively (FAO, 2023b).

Figure 2. Map of global pineapple production distribution



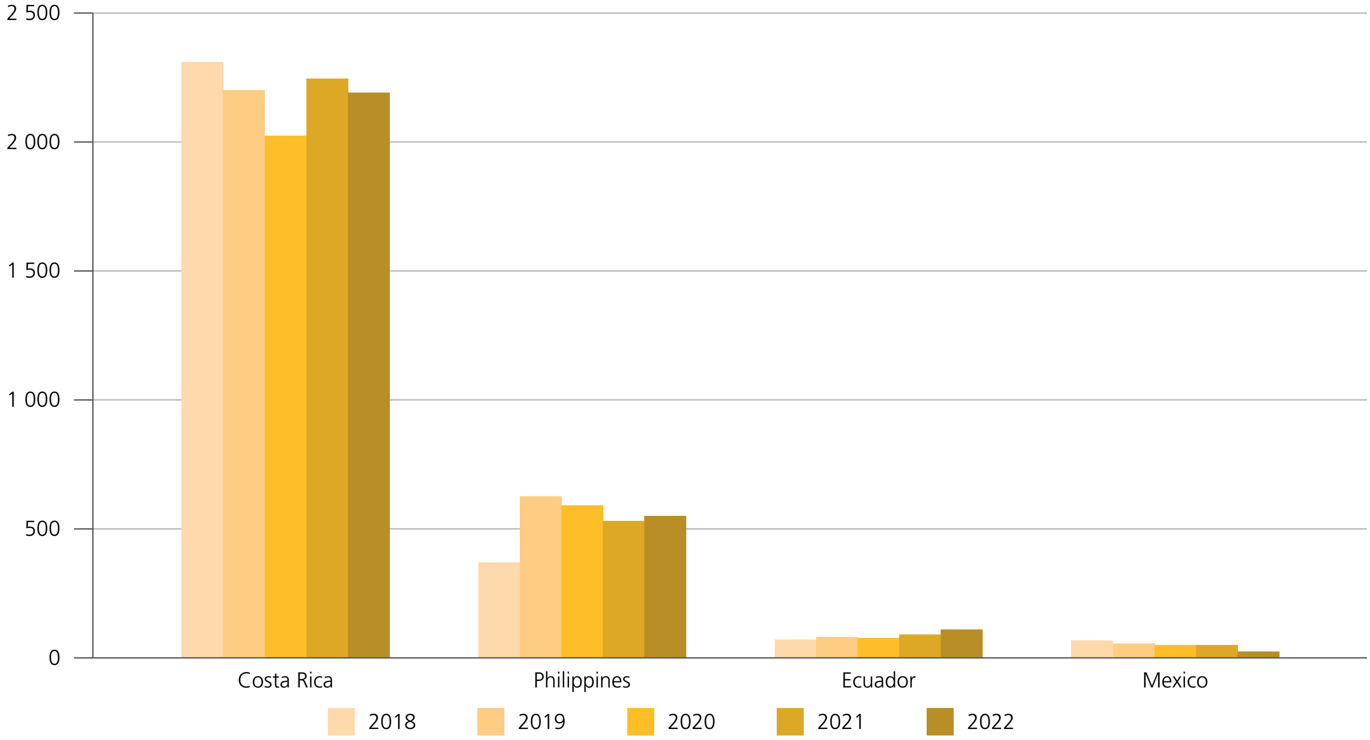
Source: Authors' own elaboration based on **FAO.** 2023. FAOSTAT: Crops. In: *FAO*. Rome. [Cited 21 March 2023]. www.fao.org/faostat/en/#data/QC

2.1.2 Global trade of pineapple

In 2021, global exports reached 3.2 million tonnes (FAO, 2022e). Costa Rica, as the world's leading producer of the market-preferred MD-2 variety pineapple, exported approximately 2.2 million tonnes, accounting for almost 75 percent of total exports, followed by the Philippines with approximately 537 000 tonnes or 17 percent of global exports (FAO, 2023b). However, based on preliminary trade data, global exports of pineapples are anticipated to fall by 1.5 percent in 2022, to just below 3.2 million tonnes, linked to cold weather conditions in Costa Rica, high energy costs and container problems (FAO, 2023a).

Figure 3 highlights the five leading exporters during the five-year period from 2018-2022 and their respective quantities, noting the dominant role in exports played by the two leading countries of Costa Rica and the Philippines. Pineapples exported from Costa Rica are primarily destined for the United States of America and European Union markets, with a split of 46 percent and 32 percent respectively in 2021 (FAO, 2022d). For the United States of America, almost 95 percent of pineapple imports originated from Costa Rica in 2021, with the remaining quantities predominantly from Mexico, Honduras and Guatemala. For the European Union, Costa Rica also supplies approximately 87 percent of the total quantity of pineapples imported, with smaller quantities coming from Ecuador, Côte d'Ivoire and Ghana. Pineapples exported from the Philippines in 2021 were primarily destined for China (40 percent), Japan (34 percent) and South Korea (14 percent) (UN Comtrade, 2023).

Figure 3. Pineapple export quantities from the leading exporters 2018–2022 (preliminary data for 2022)



Source: **FAO.** 2023. *Major Tropical Fruits Market Review – Preliminary results 2022*. Rome.

2.1.3 Country selection for the guide

Based on the above discussions, the two most important pineapple producing and exporting countries of **Costa Rica and the Philippines** were selected for further investigation by the guide into climate change effects and adaptation strategies. However, to obtain a broader understanding of climate impacts on pineapple production in other countries and regions, the additional countries of **Ecuador, Thailand and Ghana** were selected based on available information. Where possible, relevant scientific literature has also been consulted from other pineapple-producing nations and companies operating in the pineapple industry to identify innovative adaptation solutions, with useful findings emerging from countries including Brazil, the Dominican Republic, India and Malaysia. These findings have been incorporated into the guide.

2.2 Climate trends affecting key producing and exporting countries

As discussed in **Chapter 1**, tropical fruits are highly sensitive to changes in environmental factors including **temperature** and **precipitation**, which have a direct correlation with the regulatory physiological stages of fruit crops. The quality and quantity of pineapple production may be negatively affected by increased temperatures and changes in precipitation (e.g. reduced water availability/ excessive rainfall) associated with climate change. This section provides high-level information on country-level baseline climate trends associated with temperature and precipitation. It also provides information on future projections according to data from the World Bank Climate Risk Country profiles and general country-level data available on the World Bank Climate Change Knowledge Portal. The specific climate risks identified by pineapple producers and companies participating in the Responsible Fruits Project are discussed in detail in **Chapter 3** (climate risks facing pineapple production).

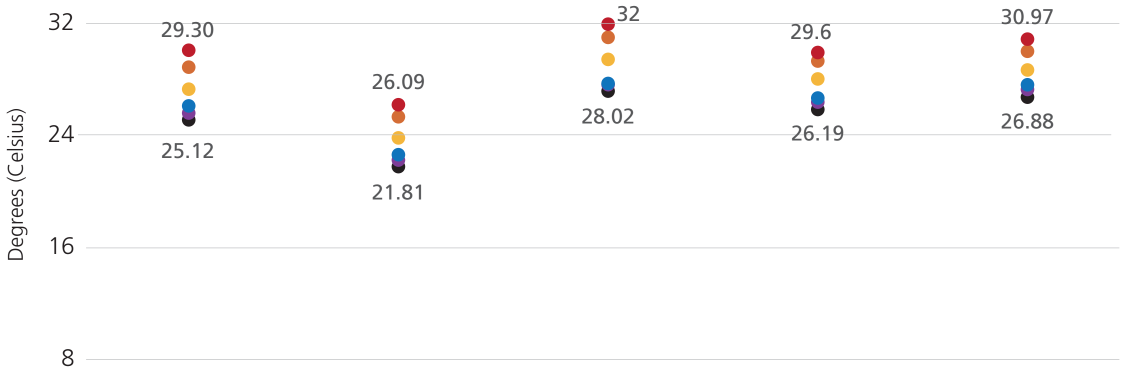
2.2.1 Climate trends associated with temperature

The World Bank estimates that average temperatures in all of the major pineapple producing countries selected in this guide will increase across all of the five emissions scenarios modelled under climate change (**Figure 4**).[7]

Considering a middle scenario (SSP2-4.5) where CO2 emissions start to decline after 2050, Ecuador is projected to see the highest peak in temperature rise among the countries studied, reaching an average of 2.02 °C by 2100. Thailand and Ghana will have warmer average weather by 1.81 °C and 1.82 °C respectively, whereas Costa Rica and the Philippines will experience an increase in their average temperatures by 1.77 °C and 1.78 °C respectively, by the end of the century.

[7] The World Bank estimated future mean temperatures until 2100 by using five possible future scenarios that consider the levels of emissions and the Shared Socioeconomic Pathways (SSPs) model. Each scenario analyses countries' emissions, mitigation efforts and development, using average temperatures between 1995 and 2014 as the reference period. The models are SSP1-1.9: Most optimistic scenario, describing a world where global CO_2 emissions are cut to net zero by 2050. SSP1-2.6: Net-zero is reached after 2050 and temperatures stabilize around 1.8 °C higher by 2100. SSP2-4.5: CO_2 emissions start to decrease after 2050 and do not reach net-zero by 2100. Progress toward sustainability is slow, with uneven development and income growth and temperatures rise 2.7 °C by 2100. SSP3-7.0: CO_2 emissions roughly double from current levels by 2100 and temperatures rise by 3.6 °C by 2100. SSP5-8.5: Current CO_2 emissions levels almost double by 2050. The global economy grows quickly relying on fossil fuels and leading energy-intensive lifestyles; the average global temperature is 4.4 °C higher.

Figure 4. Mean temperatures projected by 2100, by SSP model and pineapple producing country



	Costa Rica	Ecuador	Ghana	Philippines	Thailand
● Reference year (1995—2014)	25.12	21.81	28.02	26.19	26.88
● SSP1-1.9	25.49	22.48	28.57	26.55	27.54
● SSP1-2.6	25.85	22.66	28.62	26.78	27.71
● SSP2-4.5	26.90	23.83	29.83	27.96	28.70
● SSP3-7.0	28.34	25.38	31.38	29.07	30.26
● SSP5-8.5	29.30	26.09	32	29.6	30.97

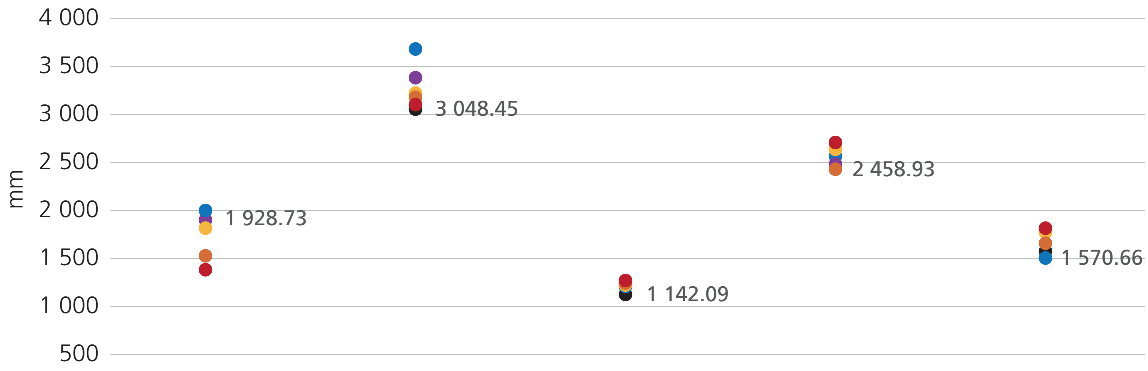
Source: Authors' own elaboration with data from **World Bank.** 2022. Climate Change Knowledge Portal for development practitioners and policymakers. In: World Bank Group [online]. Washington. [Cited 7 October 2022]. https://climateknowledgeportal.worldbank.org

According to the IPCC, an increase of 2 degrees will produce more frequent and intense extreme weather (augmented droughts, heavy rains and hailstorms), the extinction of some animals and plants, and will put the production of some agricultural commodities at risk (IPCC, 2021).

2.2.2 Climate trends associated with precipitation

Precipitation variability (distribution, frequency and quantity during the year) and long term changes have differentiated effects on pineapple production, depending on whether water deficit or excess is experienced at specific stages of the plant development. Unlike temperature trends, future precipitation patterns do not show a clear trend and vary depending on the region and producing country (**Figure 5**).

Figure 5. Projected precipitation by 2100, reference period 1995–2014, for pineapple producing countries

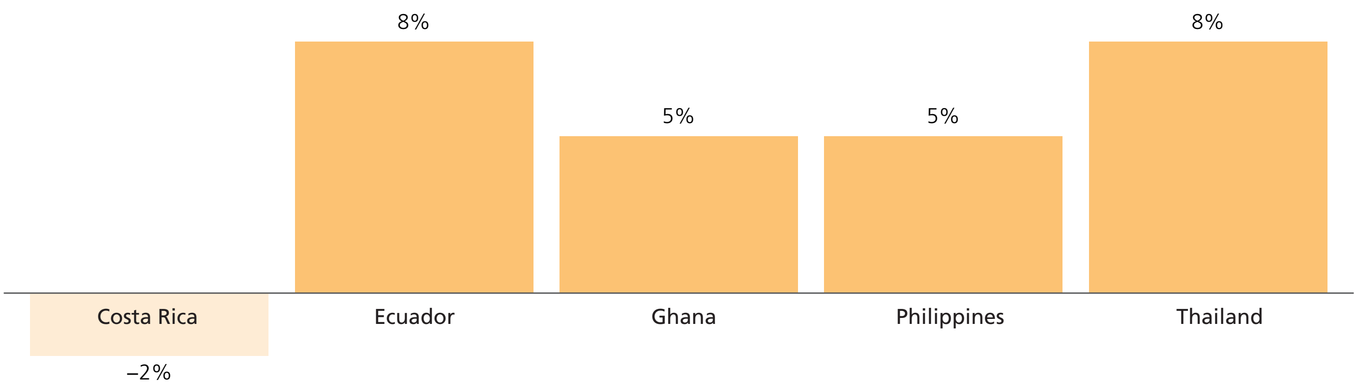


	Costa Rica	Ecuador	Ghana	Philippines	Thailand
Reference year (1995—2014)	1928.73	3048.45	1142.09	2458.93	1570.66
SSP1-1.9	1935.44	3633.12	1198.32	2516.87	1519.31
SSP1-2.6	1999.69	3434.06	1192.33	2475.05	1716.36
SSP2-4.5	1880.55	3289.46	1203.12	2571.20	1703.36
SSP3-7.0	1526.33	3280.25	1211.91	2444.95	1624.87
SSP5-8.5	1431.58	3075.93	1225.40	2609.69	1758.90

Source: Authors' own elaboration with data from **World Bank.** 2022. Climate Change Knowledge Portal for development practitioners and policymakers. In: World Bank Group [online]. Washington. [Cited 7 October 2022]. https://climateknowledgeportal.worldbank.org

Except for Costa Rica, all pineapple producing countries included in this study are predicted to see an increase in their precipitation by the end of the century, considering the middle emissions scenario. Ecuador and Thailand are expected to experience an average 8 percent increase, whereas Ghana and the Philippines will see a rise of their average annual rainfall by 5 percent. Models suggest that Costa Rica may face a decrease in precipitation of -2 percent by 2100 (**Figure 6**).

Figure 6. Precipitation change rate by 2100 using the SPSP2-4.5 model in pineapple producing countries



Source: Authors' own elaboration.

To zoom in further on the climate trends discussed above from a national perspective, **Table 2** summarizes the climate baseline and future projected temperature and precipitation trends affecting the selected pineapple producing countries according to the World Bank Climate Risk Country data and profiles for 2021 (World Bank, 2022). It should be noted that these trends are mostly reported at national level, which may/may not account for regional and local microclimate differences in key producing areas. Information on the location of pineapple producing regions within these countries is noted for reference. Localized climate risks identified by producers involved in the Responsible Fruits Project are discussed in **Chapter 3**.

Table 2. Overview of temperature and precipitation trends associated with climate change in selected pineapple producing countries

Country	Temperature projections	Precipitation projections
Costa Rica	Pineapples are produced in three regions across the country: the Huetar Norte region has the largest area dedicated to pineapple production (53 percent of total area); the Atlantic Huetar region (27 percent); and the Pacific (Brunca) region (21 percent) (CANAPEP, 2023).	
	• Temperatures are projected to rise by 1.48 °C by the 2050s and by 3.08 °C by the end of the century under a high-emissions scenario. • The number of very hot days (temperatures above 35 °C) are projected to rise from approximately 6 to 72 days of the year by the end of the century, especially in the Pacific Coast and the Northern regions. • Maximum temperatures projected to rise between 3 °C to 8 °C and minimum temperatures predicted to increase between 2 °C to 3 °C.	• Costa Rica is at risk from the increasing frequency and intensity of extreme rainfall events causing floods. Changing rainfall patterns in the country by the second half of the century suggest an earlier onset of the rainy season as well as future drying conditions. • Regionalized projections point to rainfall decreases by 2100, including a negative 13 to 24 percent reduction in the Gulf of Nicoya and the Pacific Central Zone, augmenting the likelihood of increased aridity and drought. • Increased rainfall is projected for the southern zones of the Pacific.
Ecuador	Pineapples are grown in the coastal region of Ecuador, in the provinces of Guayas, Santo Domingo de los Tsáchilas, Los Ríos, El Oro, Esmeraldas and Manabí. The majority of pineapple is grown Santo Domingo de los Tsáchilas.	
	• Temperature increases are projected to continue, with warming expected along the eastern border. Increases by 1.0 °C in the inter-Andean valley in the 2030s are forecasted. • The Amazon and Sierra Regions are expected to experience significant temperature increases by 5 °C and 4 °C, respectively, by the end of the century under a high emissions scenario. Temperatures in Coastal regions will increase by 3.3 °C in the 2090s.	• The country is expected to experience heightened dry conditions, with reduced rainfall through mid-century, with an increase in rainfall expected for the second half of the century. • Precipitation intensity is expected to increase in the Sierra and Amazon regions but is likely to decrease in the coastal areas, by up to 50 percent by mid-century. • In the coastal areas, rising seas, coupled with increased storm surges can lead to localized flooding. Landslides are also common in the mountainous areas.

Country	Temperature projections	Precipitation projections
Ghana	Pineapple cultivation is mainly concentrated in the Greater Accra, Volta, Eastern and Central regions.	
	• Temperatures are projected to increase by 1.0 °C to 3.0 °C, by mid-century and by 2.3 °C to 5.3 °C by end of the century. Projected warming will likely occur more rapidly in the northern and inland areas that the coastal regions. • Substantial increases are also expected in the frequency of hot days and nights by 18 to 59 percent by mid-century, coupled with a decrease in the number of cold days.	• Precipitation in Ghana experiences a high degree of interannual and interdecadal variability. • More erratic and intense rainfall during the wet season is expected, along with lower precipitation levels during the dry season, with larger decreases in the southern regions. Intense rainfall events are also likely to result in flooding and flash floods, as well as riverbank erosion. • Ghana is vulnerable to increasing aridity and droughts, as well as extreme rainfall events and flooding.
Philippines	Pineapple is primarily produced on the island of Mindanao (78 percent). Northern Mindanao is the top producing region for pineapples (51 percent) followed by SOCCSKSARGEN (26 percent) in Southern Mindanao (PSA, 2020).	
	• Average temperatures are projected to rise by 3.1 °C by the 2090s under a high emissions scenario. However, there is a high degree of uncertainty due to the large spatial scales used for the models. • In Luzon and Mindanao (where pineapple is grown), climate projections show a rise nearer to 3.4 °C under a high emission scenario, over the 2080–2099 period. • In south Mindanao, particularly large increases in heatwave probability are projected, with potential for year-long heatwaves by 2050. • Heat stress could see labour productivity drop by 20 percent by 2050 during peak months under the highest emissions pathway.	• Projections of local long term future precipitation trends are uncertain, yet some global trends are evident. The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different regions of Asia. • The future of precipitation in the Philippines, and particularly inter-annual variability will depend on the interaction of climate change with the El Niño Southern Oscillation phenomenon. • In terms of extreme weather events, the country is one of the most cyclone prone countries in the world, lying on the "typhoon belt". Flooding poses a considerable risk as well as exposure to earthquake, and the threat of landslides.

Country	Temperature projections	Precipitation projections
Thailand	Pineapple production takes place along the East and West Coasts of the Gulf of Thailand with the majority of production occurring in western Thailand's Prachuap Khiri Khan province.	
	• Under the high emissions pathway, average temperatures are projected to increase by 3.8 °C by the 2080s. Under all emissions scenarios, annual average of monthly maximum and monthly minimum temperatures are projected to increase considerably. • By the 2080s, Thailand is projected to experience very significant increases in the number of days in which the heat index exceeds 35 °C. • Under all emissions pathways, the likelihood of experiencing a heat wave increases considerably by 2080 to 2099. In the northern areas, the probability of heat wave per annum is 17 percent by the 2090 (under the high emission scenario).	• Studies observe an increase in annual precipitation, with an increase in precipitation during the wet season. • In Western Thailand, El Niño-related droughts have become more frequent and severe concurrently with increasing carbon levels. • The intensity of sub-daily extreme rainfall events appears to be increasing with temperature, a finding supported by evidence from different regions of Asia. • Thailand has extremely high exposure to flooding, including, riverine, flash and coastal flooding. Thailand also has exposure to tropical cyclones and their associated hazards.

Source: Climate trend data and descriptions extracted from **World Bank** (2021) and **World Bank** (2022).

2.3 Nationally determined contributions and the importance of National Adaptation Plans for the agriculture sector

In line with the above discussion on national level climate trends, it is important to understand how countries are planning and coordinating their efforts to address climate change through actions to reduce GHG emissions and implement adaptation plans. At an international level, the foundation for these actions stems from the Paris Agreement, which was signed by 196 countries on 12 December 2015 in Paris, France at the UN Climate Change Conference of Parties (COP21). The Paris Agreement is a **legally binding international treaty on climate change**. It entered into force on 4 November 2016. All five countries covered in this guide are signatories to the Agreement. Its overarching goal is to hold "the increase in the global average temperature to well below 2 °C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5 °C above pre-industrial levels" (UNFCCC, 2023). The Paris Agreement also includes the Global Goal on Adaptation, which aims "to increase the adaptive capacity, strengthen the resilience and reduce vulnerability to climate change, to contribute to sustainable development and ensuring an adequate adaptation response" (UNFCCC, 2015). In recent years, world leaders have stressed the need to limit global warming to 1.5 °C by the end of this century. According to the IPCC, crossing the 1.5 °C threshold risks unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall. To achieve this, GHG emissions must peak before 2025 at the latest and decline 43 percent by 2030 (IPCC, 2023).

Implementation of the Paris Agreement by each signatory is achieved through national climate action plans known as nationally determined contributions (NDCs), which outline the efforts made by each country post-2020 to reduce national GHG emissions and adapt to the impacts of climate change. Each country must set targets for reduction of GHG emissions, outline how they plan to achieve these through mitigation measures, and describe their strategies for implementing adaptation practices across prioritized sectors. NDCs are submitted every five years to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. In order to enhance the ambition over time, the Paris Agreement states that successive NDCs must represent a progression compared to the previous NDCs and reflect its highest possible ambition. The NDCs serve as a collective way to track global progress on climate goals and signal whether global warming can stay well below the threshold of 1.5 °C. All six countries covered by the guide have submitted NDC reports[8] to the UNFCCC since 2020.

A review of these reports indicates that mitigation targets and specific programmes to reduce emissions remain the focus of NDCs. While adaptation efforts are mentioned across the six reports, in most cases these are in more general/abstract terms than those related to mitigation, with unclear indication of how these efforts will be monitored and measured. These findings were also confirmed in the UNFCCC 2022 NDC Synthesis Report which reviewed 166 of the NDCs including 142 new or updated NDCs, as well as by the 2023 NDCs Global Update Report. These reports found that while the adaptation component in the updated NDCs had improved, further work is still needed to introduce time-bound quantitative adaptation targets and the associated indicator frameworks across all reports. One of the challenges to encouraging greater clarity on adaptation strategies and targets, is the lack of a standardized reporting framework for adaptation in the NDCs. Some countries have clearly defined their adaptation programmes and begun to set targets in their NDCs (e.g. Kenya), while others remain more abstract.

The development and implementation of National Adaptation Plans (NAPs) is an important instrument to operationalize the implementation of adaptation goals included in the NDCs. Climate change adaptation in the agriculture sectors is among the foremost priorities identified in developing countries' national climate plans. More than 95 percent of developing countries that specified adaptation priorities and/or actions in their NDCs referred to the agriculture and land use sectors, with 78 percent referring to specific actions related to ecosystems and natural resources (FAO, 2016, 2017a; Crumpler *et al*, 2021). However, these plans are often weak when it comes to the detail on how efforts will be targeted towards supporting adaptation in agriculture. They may not cover critical aspects of adaptation planning needed not only to support agriculture (including crop and livestock production, fisheries and forestry) but also food security and nutrition. In addition, a gender-responsive approach is also needed in NAP-Agriculture planning to recognize the disproportionate impact of climate change on the livelihoods of women, girls and youth, and begin to address the

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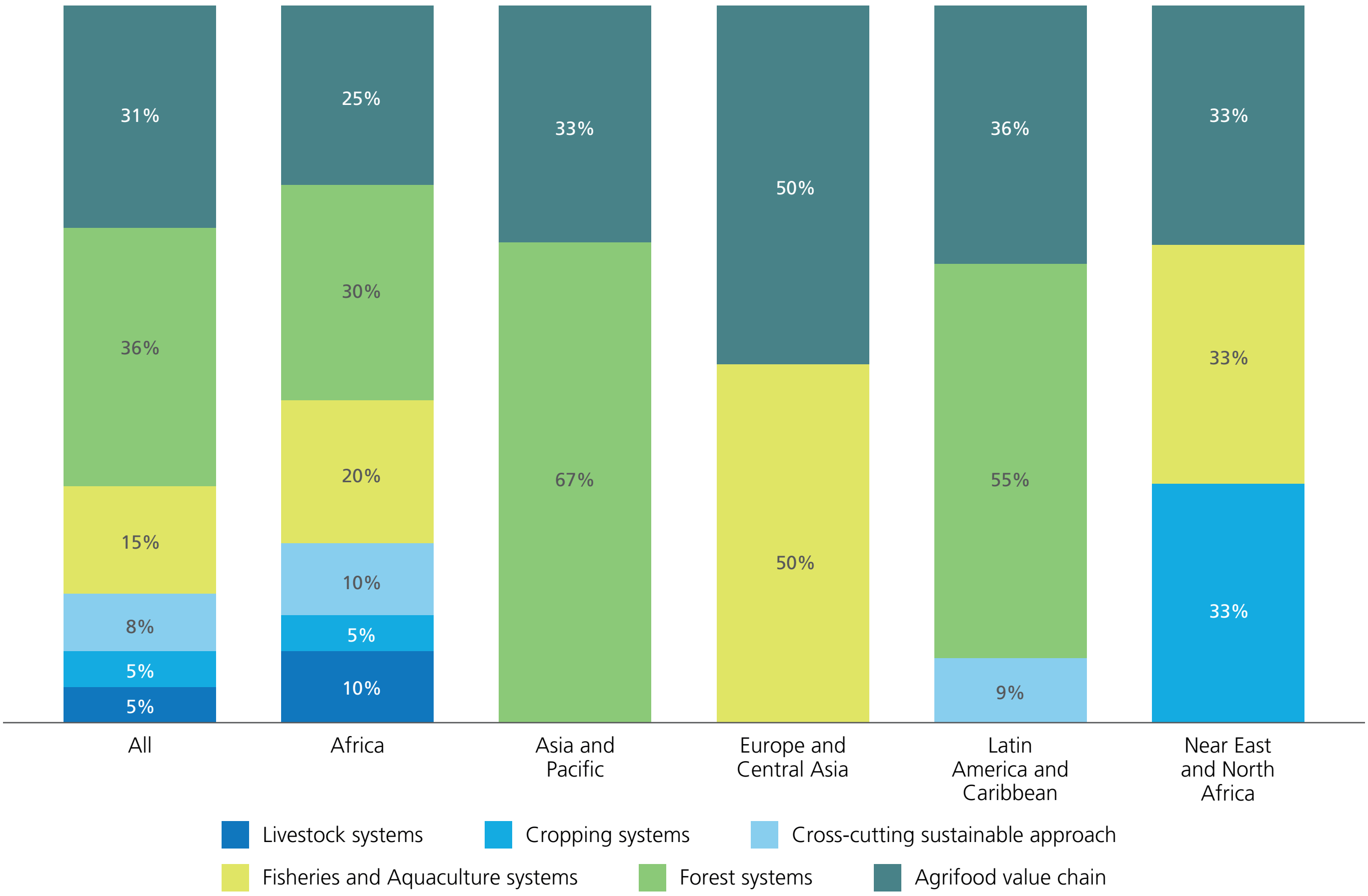
8 NDC reports for all countries covered by the guide are available at the NDC Registry managed by UNFCCC. Reports are available for Costa Rica, Ecuador, Ghana, the Philippines and Thailand.

structural inequalities (e.g. in policies, laws, norms, institutions, etc.) that underlie many of the different adaptation challenges that women and men may experience (FAO, 2018a).

NDCs and NAPs also recognize the critical need to involve private companies in the agriculture and land use sectors. A recent analysis on the NDCs and NAPs submitted to date indicate that while 60 percent of countries engage in consultations with the private sector in the NDCs planning process, only 10 percent have active collaboration (Crumpler *et al.*, 2021). This trend is observed across all regions, though the Latin America and Caribbean region shows the greatest active collaboration between governments and the private sector in the NDCs planning (*ibid.*).

The main entry points for climate action dialogue across all regions are linked to mitigation and/or adaption potential in forest systems (36 percent) and agrifood value chains (21 percent; see **Figure 7**), both of great relevance to the avocado industry operating in the countries selected for analysis in this guide.

Figure 7. Private sector entry-points in the NDCs planning related to the agriculture sectors, by region and subsector



Source: **Crumpler, K., Abi Khalil, R., Tanganelli, E., Rai, N., Roffredi, L., Meybeck, A., Umulisa, V., Wolf, J. and Bernoux, M.** 2021. *2021 (Interim) Global update report – Agriculture, Forestry and Fisheries in the nationally determined contributions*. Environment and Natural Resources Management Working Paper No. 91. Rome, FAO. https://doi.org/10.4060/cb7442en

To address the abovementioned challenges, since 2015, FAO and the United Nations Development Programme have partnered to work with countries to integrate adaptation solutions specifically for the agriculture sector as part of the broader NAPs developed by countries. The programme titled "Integrating Agriculture in National Adaptation Plans (NAP-Ag)" has worked with 11 countries, to identify and integrate climate adaptation measures for the agriculture sector into national planning and budgeting processes, in support of achieving the Sustainable Development Goals and the Paris Agreement. Two of the key pineapple producing countries, the Philippines and Thailand, are included in NAP-Ag programme. While the plans developed do not focus on the tropical fruit sector, they warrant further consideration given the identification of climate risk factors for agriculture in the plans, and the adaptation measures proposed, which are also relevant for tropical fruit production (e.g. water management, soil conservation, protection of biodiversity, agroforestry and early warning systems). Some examples of the support provided by the NAP-Ag programme to these countries are highlighted in **Table 3**.

Table 3. Summary of the support provided by the NAP-Ag Programme to countries for the development of their NAPs

Country	NAP-Ag Support
Philippines	Since 2016, NAP-Ag support in the Philippines has been aimed at deepening a number of priority areas: greater integration of climate change adaptation and disaster risk reduction into agriculture sector plans and operations; enhanced understanding on landscape-based adaptation planning; better integration of national and local adaptation planning for the agriculture sectors; improved forecasting for crops and fisheries; and improved capacity for prioritizing, monitoring and evaluating gender-sensitive adaptation options for the agriculture sectors.
Thailand	NAP-Ag Supported the development of Thailand's Agriculture Strategic Plan on Climate Change (ASPCC) (2017–2021). The plan provides a synthesis of knowledge on observed and projected climate change impacts on the agriculture sector in Thailand, and also outlines prioritized response strategies. Climate Change Adaptation Priorities: • Priority 1: Water management: i) Integrated and participatory water resource management; ii) increasing water use efficiency; iii) expanding irrigation areas; and iv) increasing number of farm ponds for water storage. • Priority 2: Sustainable Soil Management:i) Preventing soil degradation (such as planting cover crops, and crop rotation); ii) rehabilitating degraded soils (such as soil condition analysis and organic fertilizer promotion); and iii) optimising agricultural land use through agricultural zoning (by using agricultural-mapping tools). • Priority 3: Strengthening farmers' climate resilience:i) Climate change risk mapping for all main crops; ii) promoting climate risk insurance (index-based insurance); iii) developing the climate-resilient index for the agriculture sector; iv) promoting integrated farming and sustainable agriculture (organic farming and New Theory Agriculture); v) promoting technology transfer on precision farming and biotechnology; vi) developing early warning systems (EWS) for agriculture sector; and vii) promoting market-based policies and economic incentive for climate action. • Priority 4: Strengthening measures to support farmers' and businesses' ability to adapt: i) Develop measures to compensate and support climate adaptation and resilience to farmers and businesses, and ii) strengthen measures, mechanisms, and institutional structure as appropriate.

Source: Adapted from **FAO.** 2023. Integrating Agriculture in National Adaptation Plans. [Cited on 2 May 2023]. www.fao.org/in-action/naps/partner-countries

In recent years, work under the NAP-Ag programme has also progressed to include support for the design of monitoring and evaluation (M&E) systems for adaptation in the agriculture sectors to be incorporated into NAPs (FAO and UNDP, 2023). According to FAO and UNDP (2023), countries face several challenges in doing M&E of adaptation, including the long-time scales over which climate change impacts unfold; the uncertainty of climate impacts; context specificity and lack of common indicators; attribution of impact to adaptation and/or development interventions; and access to and availability of relevant climate data. However, progress is ongoing and there is recognition that it is essential to link M&E systems to broader adaptation planning and implementation processes, including NAPs and NDCs.

In the context of the tropical fruit industry, understanding how specific commodity sectors like pineapple production and export can contribute towards the achievement of mitigation and adaptation targets set out in the NDCs and NAPs is useful. It may help the industry to align their efforts with those at a national and sub-regional level where they exist and demonstrate to policy makers that collective efforts are being made by industry to support these plans. Specific initiatives such as the monitoring of carbon and water footprints with open-source tools (such as the one currently under development by the Responsible Fruits Project for the pineapple industry) could help producer and exporter associations to demonstrate in a concrete way how adaptation and mitigation efforts are being supported in line with national strategies, plans and objectives. Similar approaches should be considered to monitor and evaluate adaptation practices identified in **Chapter 4** of the guide, so that industry-led/public–private partnership initiatives can be highlighted as contributing towards the delivery of national adaptation goals.

Chapter 3.

Climate risks facing pineapple production

As discussed in **sub-section 2.2.1** of **Chapter 2**, an increase in average temperatures is predicted by the end of the century for all pineapple-producing countries identified in the guide. This will lead to more frequent and intense extreme weather events, with major impacts on the quality of pineapple at pre- and post-harvest stages, and thus on market potential for companies and associations.

Unlike temperature trends, future precipitation patterns do not show a consistent trend and vary depending on the region and producing country (see **sub-section 2.2.2**). Except for Costa Rica, where a decrease in precipitation is projected, all other pineapple producing countries included in this study will likely see an increase in precipitation by the end of the century, with Ecuador and Thailand expected to experience the highest average increase by 2100.

Considering these future trends, this chapter presents a summary of climate risks identified through a review of the scientific literature and consultations held with producers and associations from the pineapple industry. Understanding these risks can help pineapple producers, associations and companies consider future climate risks in decision-making processes to manage and mitigate potential impacts accordingly. Each risk:

- identifies and describes the effects of the risk on pineapple production;
- illustrates other potential impacts that climate change and extreme weather events may have on social and economic dimensions of pineapple production; and
- highlights the climate risks experienced in different pineapple producing countries

The main climate risks and some impacts on pineapple production are summarized in **Table 4**.

Table 4. Main climate risks and other associated impacts and threats for pineapple production

Climate variables	Risks and impacts identified	
Temperature	Increasing temperatures	Extreme heat
	Frost and low temperatures	Hailstorms
Precipitation	Intense rainfall	Water shortage
	Drought	Changes in rainfall patterns
Mixed and other	Precocious flowering	Spread of pests and diseases
	Soil erosion	Strong winds

3.1 Temperature

Good fruit quality can be achieved by combining relatively cool night temperatures, sunny days and day temperatures ranging from 21 °C to 29.5 °C, and not exceeding 32 °C (Hossain, 2016). However, depending on the producing region, these thresholds may vary. For example, Ghana's pineapple growing regions range from 20 °C to 36 °C (Williams, Crespo and Atkinson, 2017). Temperatures outside these ranges can severely affect the plant development and fruit quality as explained below.

High temperatures

For every 1 °C above 32 °C, plant growth rates decrease rapidly and above 35 °C pineapple growth can also be retarded (Government of Australia, 2008). High temperatures also have an influence on fruit quality. **Table 5** summarizes the main effects that high temperatures have on pineapple development and quality.

Table 5. Increased temperature impact on pineapple production

Production stage	Impact
Flowering	Night temperatures above 25 °C accelerate flowering, leading to precocious flowering and uneven production.
Fruit development	Temperatures exceeding 32 °C cause the production of unevenly shaped fruits, especially of crowns, which constitute one of the main planting materials.
Quality	High temperatures (above 35 °C) and associated solar radiation affect the pineapple skin and may enable the conditions for the proliferation of diseases. Depending on the degree of the damage, sunburnt fruit may not meet international market requirements.
Harvest	High differences in temperature between day and night of 8 to 14 °C also reduce crop yields (Custódio *et al.*, 2016).

As seen in Table 5, the expected warmer weather will have a differentiated effect on pineapple production, depending on the development phase when higher temperatures are experienced. High temperatures are generally of minor concern during vegetative growth of pineapple as leaves tend to have a good tolerance to high temperatures (Bartholomew, Paull and Rohrbach, 2003; Williams *et al.*, 2017). However, during the plant development phase, high temperatures can lead to the formation of corky tissue in fruits, deforming the fruit. Also, temperatures above 32 °C can cause the death of plants due to stomatal closure and decrease of transpiration process (Cespedes *et al.*, 2018).

Elevated temperatures also produce higher water evaporation, decreasing in the amount of water available in the soil and in the environment. This has a negative impact on the absorption of nutrients by the plant, and thus, on its physiological development. For example, it can cause problems in the development of the fruiticles (pineapple eyes) of the fruit, which is perceived as a loss to the aesthetic quality of the fruit (Cespedes *et al.*, 2018).

During the flowering phase, warmer temperatures, accompanied by other humidity factors, also increase the incidence of major pineapple pests such as Thecla (*Strymon basilides*) and mealybugs (*Dysmicoccus brevipes*), which are attracted by the coloration of pineapple flowers (more details on pest and diseases are offered below).

Changes in solar radiation

Optimum luminosity for plant and fruit development is around 1500 hours per year (Vargas *et al.*, 2018). Solar radiation higher or lower than this level will have different effects on pineapple production and quality.

Very high temperatures can lead to increased solar radiation, damaging the quality of the fruit and promoting the spread of pests and diseases (Vargas *et al.*, 2018). Fruit sunburn, one of the main problems of increased radiation, occurs during periods of high irradiance and it can result in significant losses of fruit. Sunburn occurs when a localized area of the fruit is directly exposed to the sunlight, resulting in elevation of flesh temperatures. Sunburn can injure plants and fruits at different levels. It can have minor effects by merely discolouring the shell or cause severe damage making fruits unsuitable for commercial purposes.

Sunburn during inflorescence development can produce severely misshapen fruits. The direct impact of sunrays on pineapple plants during the flower induction phase causes an increase in fruits damaged by corky tissue, affecting the quality and aesthetics of the fruit and lowering the marketable yield (Cespedes *et al*., 2018). During the ripening phase, severe sunburn can make the injured area become translucent and dried out (Bartholomew, Paull and Rohrbach, 2003).

Conversely, low sunlight intensity can cause physiological delays in plant development since the plant does not receive enough energy necessary to perform photosynthetic processes. In addition, internally the plant undergoes changes in its morphology since it goes from vegetative state to reproductive stage, accelerating the natural flowering. As this process is not homogeneous within the whole pineapple plantation, it causes an increase in production and harvest costs and lowers yields (Cespedes *et al*., 2018). Likewise, low radiation may promote the formation of opaque fruits during the ripening phase, which are not suitable for export (Vargas *et al*., 2018).

High temperatures and radiation also have impacts on the health and safety of workers in pineapple plantations and packing areas. Increased and persistent exposure to sunlight and heat increases the risk of dehydration, the prevalence of skin-related diseases and other heat-stress symptoms, while reducing productivity among workers. Heat stress in workers and resultant labour productivity decline has been identified as a major challenge associated with climate change in the future in countries such as Costa Rica, Ecuador and the Philippines (World Bank, 2022).

Lower temperatures

Extreme low temperatures are mainly caused by the entry of cold fronts, sometimes leading to temperature drops from 30 °C to less than 15 °C in very short times. This phenomenon has been observed in Costa Rica and the Dominican Republic. Sudden drops in temperature cause great problems in the development of the pineapple plant, which is highly susceptible to low temperatures. A sudden decline in temperature can accelerate natural flowering, especially among plants that are already in the flowering phase or are morphologically prepared to bloom (Cespedes *et al*., 2018). This causes unevenness in the ripening and harvesting time, causing economic losses to producers (Williams *et al*., 2017).

Likewise, pineapple plants do not tolerate frost, and prolonged cold periods at or temperatures below 0 °C affect plant growth by destroying the plant canopy, delaying ripening and altering the quality of the fruit, making it more acidic (OGTR, 2018).

Low temperatures may also affect the proliferation of some diseases. The development of the fungus *Penicillium funiculosum* flourishes in temperatures oscillating from 16 °C to 20 °C (Manik *et al*., 2019).

3.2 Precipitation

In general, pineapple does not have high water requirements as the plant is highly efficient at using the water available in the environment. An estimated annual rainfall from 1000 mm to 1500 mm with correct distribution throughout the year is sufficient for its development (de Azevedo *et al.*, 2007). However, depending on the soil properties, humidity levels and temperatures in the producing regions, these thresholds may vary. For example, in Ghana, pineapple grows with annual rainfall of 600 mm to 4000 mm (Williams, Crespo and Atkinson, 2017). This gives pineapple plants an inherent ability to resist dry seasons and arid conditions, yet extended drought periods will also affect production. On the other side, pineapple plants are particularly sensitive to increasing rainfall and atmospheric moisture. Rainfall variability affects pineapple production differently depending on the production stage (see **Table 6**).

Table 6. Summary of impacts of water deficit or excess on pineapple production

Production stage	Impact
Flowering	Irregular rainfall patterns (prolonged rains or dry days) render artificial flowering ineffective and results in repeated applications with increased costs and inhomogeneous flowering affecting maturity and commercialization.
Fruit development	Very low rainfall causes poor development of the plant, while continuous precipitation leads to the complete failure of the crop. Long dry or wet periods during sucker development result in failure of suckers to develop. No rainfall after planting affects shooting and plant development. Compounded with rising temperatures, water deficits can lead to higher evapotranspiration, reducing soil moisture and causing water stress during production.
Quality	Abundant water increases the presence of diseases, such as *Chalara paradoxa*. Water excess largely stimulates stem growth and a large core, which is disadvantageous for those companies processing fruits, mainly for canning. High rainfall also increases water content in the fruit, heightening its acidity levels and reducing the sugar content, ultimately altering the fruit's taste and texture.
Harvest	Water surplus increases the susceptibility of the crop to fungi causing heart rot and other post-harvest defects which deteriorate the fruit quality.

Sources: **Joy, P. & Sindhu, G.** 2012. *Diseases of pineapple (Ananas comosus): Pathogen, symptoms, infection, spread and management*. [Cited 15 June 2023]. www.researchgate.net/publication /306017784_DISEASES_OF_PINEAPPLE_Ananas_comosus_Pathogen_symptoms_infection_spread_management; **Manik, T.K., Sanjaya, P., Pandu Pradana, O.C. & Arflan, D.** 2019. Investigating local climatic factors that affected pineapple production in Lampung Indonesia. *International Journal of Environment, Agriculture and Biotechnology*, 4(5): 1348–1355. https://doi.org/10.22161/ijeab.45.8; and **Williams, P.A., Crespo, O., Atkinson, C.J. & Essegbey, G.O.** 2017. Impact of climate variability on pineapple production in Ghana. *Agriculture & Food Security*, 6(1): 26. https://doi.org/10.1186 /s40066-017-0104-x

Low precipitation and drought conditions

Despite the high resistance of pineapple to arid conditions, lack of water at any stage of plant development can result in low productivity. Water deficit stress has been shown to affect the size and quality of pineapple plants and fruits (Abdullah *et al.*, 2011). Water deficit can lead to physiological delays and loss of plants, since the availability and absorption of nutrients necessary for their development is reduced (Cespedes *et al*., 2018). Therefore, if the annual rainfall is less than 500 mm or if droughts are projected, the implementation of supplementary irrigation systems is essential to ensure the viability of the production (Hossain, 2016).

High precipitation

Excess rainfall has a direct impact on fruit quality and development, as well as on the prevalence of pests and diseases. Water excess produced by intense precipitation can lead to soil saturation and lower soil oxygen levels. Compounded, these phenomena reduce the development of roots and vegetative growth, cause fruit colour loss, lower sugar content (low brix degrees) and yield (Cespedes *et al*., 2018). In the absence of good drainage systems and good soil structure, waterlogging can occur. When plants are waterlogged, oxygen around roots is deficient as aerobic respiration reduces and anaerobic respiration increases. The rate of photosynthesis also decreases, affecting plant growth (Shu *et al*., 2019). Iron toxicity can also occur in waterlogged soil. The amount of ferrous in the soil solution can cause nutrient imbalances which affect plant growth (Chairani *et al*., 2018). At the same time, the ethylene in the above-ground tissues can increase as a result of waterlogging, which promotes faster fruit maturity.

In regions where heavy and increasing rainfall is predicted, pineapple plants will have higher susceptibility to pests and diseases. For example, soil saturation and anoxia, combined with higher temperatures enable the incidence of some of the main pineapple fungal diseases, such as *Phytophthora* and *Fusarium* E. *carotovora*. In some cases, waterlogging can lead to death of plants within 15 days due to root and plant rot (Australian Government, 2008).

As pineapple is generally a rainfed crop, good water management practices need to be ensured to prevent waterlogging and soil saturation when heavy or constant rains occur. The plantations should not be allowed to become waterlogged for any extended length of time, and the monitoring of the soil moisture throughout the growing period is advised (Verma, 2018).

3.3 Soil health

Pineapple requires soils with high permeability since poor drainage increases the risk of pathogen attacks in the roots. Loose and aerated soils with good drainage are required for optimal production (MAG, 1991). A well-drained, sandy loam with a high content of organic matter is best for pineapple cultivation (Verma, 2018).

Poor soil health, translated into soil erosion and land degradation, can be caused by wind, water currents from streams or heavy rainfall, temperature changes or the inadequate use of the resource (e.g. poor implementation of soil management practices, overuse of agrochemicals, tillage). Other causes contributing to soil health loss are deforestation, land use change (from forest or grasslands to agriculture) and overgrazing (Leon *et al*, 2012).

Climate change is likely to exacerbate issues linked to soil health, facilitating soil erosion processes. As discussed in **Chapter 2**, rainfall is expected to increase in some of the main producing pineapple regions, such as Ecuador, Ghana, the Philippines and Thailand, which increases the risk of soil erosion through higher topsoil runoff. This is particularly concerning in production areas which do not have good drainage, with steep slopes, with minimum vegetation cover, and already degraded soils (Martínez, Menjívar and Saavedra, 2022). The erosion may in turn increase the frequency of waterlogging produced by intense rainfall, creating the conditions for the proliferation of fungal pathogens and weeds, particularly in places where these are already problematic (Howden, Newett, and Deuter, 2005). Warmer weather may result in higher soil temperatures and evaporation, affecting moisture and overall structure of the soil. This may lead to increased water demand for irrigation (*ibid.*).

The use of excessive tillage for soil preparation, synthetic pesticides and herbicides to manage pests, diseases and weeds, and the use of heavy machinery can all increase the risks to soil erosion, including soil pollution, fertility decline and salinization (Martínez, Menjívar and Saavedra, 2022). Some of these soil degradation issues have been observed in pineapple producing areas in Costa Rica, the Dominican Republic and Malaysia, according to the companies participating in the project.

Overall, soil and land degradation have negative impacts on production, by lowering productivity and negatively affecting ecosystems and biodiversity adjacent to agricultural production areas (European Commission, 2021).

3.4 Strong winds

Strong winds can cause leaves to rub against each other and the physical damage provides points of entry for fungal pathogens. Exceptionally strong winds caused by hurricanes, cyclones and typhoons can severely damage all parts of the plant or uproot it, leading to significant loss of plants and post-harvest damage to fruit (Bartholomew, Paull and Rohrbach, 2003). These impacts cause losses in production and income and increase costs of re-planting. Extreme weather events such as these are predicted to increase by the end of the century in pineapple-producing countries including Costa Rica, the Philippines and Thailand under the different climate change scenarios (World Bank, 2022).

Strong winds can also cause soil erosion, by promoting the loss of soil moisture and stress from physical damage. Like intense rainfall, strong winds can also negatively impact production infrastructure, including irrigation and drainage systems.

3.5 Pests and diseases

Climate change is expected to exacerbate the frequency and resistance of pests and diseases (Skendžic *et al.*, 2021). Warmer temperatures and changes in humidity levels in the main pineapple producing regions will bring about shifts in the geographical distribution of pests, changes in seasonal phenology (e.g. timing of outbreak), and population dynamics (e.g. survival) (IPCC, 2021).

The projected increase in pests, compounded with more stringent phytosanitary requirements and agrochemical use regulations from the importing markets pose a sustainability and resilience challenge to the pineapple sector. The main pests and diseases observed in pineapple production in Costa Rica are listed in **Table 7**. Many of these pests and diseases are also relevant for other pineapple producing countries.

Table 7. Prevalent pests and diseases present in pineapple production in Costa Rica

Pest or disease	
Black rot *(Thielaviopsis sp.)*	*Chalara paradoxa*
Mealybug *(Dysmicoccus brevipes)*	*Fusarium guttiforme*
Symphilids *(Hanseniella* spp., *Scutigerella* spp., *Symphylella* spp.)	*Penicillium funiculosum*
Pineapple Weevil (*Metamasius dimidiatipennis*)	Root-knot nematode (*Meloidogyne javanica*)
Phytophthora cinnamomi* and *Phytophthora nicotianae	Root lesion nematode (*Pratylenchus brachyurus*)
Scale *(Diaspis bromeliae)*	White grubs (*Phyllophaga* sp.)
Thecla *(Strymon basilides)*	Soldier worm (*Elaphria nucicolora*)

Source: Adapted from **Monge Muñoz, A.** 2018. Guía para la identificación de las principales plagas y enfermedades en el cultivo de piña (Guide for the identification of the main pests and diseases in pineapple cultivation). Universidad de Costa Rica, Costa Rica. 46.

3.6 Soil erosion

Natural flowering in pineapple varies from year to year according to the seasons and producing regions, and its success increases in the areas of higher altitude and latitude. In the main producing regions in Costa Rica, the natural occurrence of flowering varies from 20 to 80 percent (Gonzalez, 2010).

As the pineapple industry has expanded globally, it has become common to force pineapple flowering (i.e. artificial flowering) to ensure that pineapple production and supply are available throughout the year. As a result, natural flowering before the scheduled forcing date has become a significant problem for the industry, because it affects crop management, harvesting and fruit sales. In some areas, particularly subtropical regions, precocious flowering may cause serious yield losses as it results in the production of fruits that are too small or too few at a given time to be worth harvesting (Bartholomew, Paull and Rohrbach, 2003).

As discussed earlier in this chapter, climate change impacts including increased night temperatures or a sudden sharp decline in temperature can accelerate natural flowering, and irregular rainfall patterns (prolonged rains or dry days) can also render artificial flowering ineffective. Thus, the increasing incidence of precocious flowering in pineapple plantations should be considered an important economic risk for producers associated with climate change.

Chapter 4.

Climate change adaptation strategies for pineapple production

Following on from **Chapter 3** and the discussion on climate risks and impacts on pineapple production, this chapter presents 12 adaptation practices identified through consultations with key informants from the industry and in the scientific literature. The practices recommended are closely linked to different approaches that promote both climate adaptation and sustainability across multiple dimensions. These include climate-smart agriculture, agroecology, regenerative agriculture and digital agriculture.

The selected practices can also contribute directly to the resilience of production systems to future climate events. Each practice:

- identifies which climate risks can be minimized, or in some cases prevented through the adoption of the practice;
- gives a brief description of the practice and how it is implemented;
- illustrates other potential co-benefits on environmental, economic or social dimensions; and
- highlights an example of implementation in practice by a producer association or company where available.

Table 8 summarizes the practices included in this chapter and provides an overview of the climate hazards and associated impacts they address. As seen in the table, implementing one adaptation practice may help to address multiple risks, and several practices combined may strengthen the overall resilience of the production system.

The examples included in this chapter highlight innovative approaches that pineapple growers, companies and associations are taking to adapt to climate change. These practices are for illustration purposes only. They have not been validated in the field by FAO nor officially endorsed.

Table 8. List of climate adaptation practices and climate hazards and impacts they address

Adaptation practices / Climate hazards and impacts	Intense rainfall	Changes in rainfall patterns	Extreme heat	Frost and low temperatures	Strong winds	Hailstorms	Increasing temperatures	Water shortage	Drought	Soil erosion	Solar radiation	Spread of pests	Alternate bearing
Agroforestry	X		X	X	X				X	X	X	X	X
Artificial flower induction	X	X					X						X
Crop rotation	X						X		X	X	X	X	
Drainage systems	X	X								X		X	
Early warning systems	X	X	X	X	X	X	X	X	X	X	X	X	X
Integrated pest management		X					X			X	X	X	
Intercropping								X	X	X	X	X	
Integrated water management	X	X	X		X			X	X	X		X	X
Mulching and cover crops	X	X	X	X	X	X		X	X	X	X	X	
Solar protectors			X	X	X	X					X		X
Waste management										X		X	
Windbreaks and living fences			X		X	X				X		X	X

Note: You can click on the different practices for more details.

4.1 Agroforestry

Climate risks and impacts addressed: strong wind, extreme heat, wind and intense rainfall and soil erosion. The microclimate generated by the presence of trees and vegetative cover can also help to minimize the effects of **droughts** and **frost**. These systems can also contribute to **pest control**. Co-benefits include diversifying production, which can generate an additional income source for producers in case of reduced quality and yield of pineapple production. Agroforestry can also help to reduce the use of external inputs, such as fertilizers and pesticides.

The practice:

Agroforestry is a technique of combining flora species with the predominant production system, in this case, pineapple production.[9] Agroforestry systems are designed to create common benefits from the interaction among different species, without creating competition. The association optimizes biodiversity and other factors, including ecosystem services (nutrient and water cycling), improves soil quality and nutrient availability, and enhances pests and diseases management (Lugo, 2018). The implementation of agroforestry systems is recommended on degraded areas that are suitable for farming and/or forestry to recover forest areas without sacrificing pineapple production. An example of an agroforestry system can be seen in **Figure 8**.

Figure 8. Pineapple plantation grown in an agroforestry system in Ghana

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[9] Small ruminants or poultry can also be integrated in the systems, but the introduction of livestock is not discussed in this document due to the nature of the production systems analysed.

Agroforestry practices implemented in pineapple plantations can be more productive and more economically profitable than monoculture systems. A study conducted in Mexico found that increasing the presence of woody species can help to increase yield and plantation density (Rosales-Adame *et al.*, 2014). Some recommended woody species are *Arecaceae*, *Bignoniaceae*, *Anacardiaceae*, *Lauraceae*, *Malpighiaceae*, *Meliaceae*, *Moraceae*, *Rutacea* and *Salicaceae*. Other fruit or non-timber tree species with commercial purposes are banana (*Musa cavendishii*), papaya (*Carica papaya*), orange (*Citrus sinensis*), lime (*Citrus aurantifolia*), lemon (*Citrus limon*), avocado (*Persea americana Mill.*), coffee (*Coffea arabica L.*) and mango (*Mangifera indica L.*), among others. Please refer to the section on **windbreaks and living fences** for a list of other trees that can be used in agroforestry systems (**Table 11**).

Ecosystem benefits of agroforestry also include disaster risk reduction. The presence of trees and shrubs promotes soil anchoring/stabilization and reduces storm runoffs, leading to lower damages and losses in infrastructure and crops. This also results in savings associated with expensive infrastructure solutions, such as drainage ditches or storm sewers (Schick *et al.*, 2018). Studies have shown that planting trees and shrubs between crops and around land plots (see **windbreaks and living fences**) can help prevent soil erosion, restore fertility and provide shade to pineapple. The incorporation of perennials also contributes to absorbing more carbon, thereby offsetting and mitigating some climate change effects (Oloo *et al.*, 2013).

However, it is important to highlight that the ecological productivity of agroforestry systems is closely related to how the system is designed, namely, the types of plant species integrated in pineapple plantations and the plant density in the field. Considerations of plant selection are needed, as canopy levels, shade tolerance, nutrient and water requirements vary among pineapple and other plants, with potential impacts on pineapple plant and fruit development and yield at different stages.

On the economic side, considerations should be given to the costs related to the cultivation of other commercial and/or non-commercial crops (e.g. labour, machinery, equipment, seeds, inputs) as well as the potential supplementary income generated by these, in order to determine the economic viability of the system.

Careful deliberation is needed in the selection of plants to be incorporated in agroforestry systems. As in the case of **windbreaks and living fences**, non-native species used in agroforestry can become invasive if their natural enemies are not present in the environment in which they are incorporated. Thus, it is highly important to select complementary species that do not compete with both pineapple plants and local biodiversity.

4.2 Control natural flowering through artificial induction

Climate impacts addressed: the practice does not respond to specific climate hazards. Instead, artificial induction of flowering aims to reduce the potential for early natural (or precocious) flowering stimulated by higher temperatures and increased precipitation. The incidence of early flowering has impacted on production planning by reducing uniformity in production times and affecting trade. Artificial induction of flowering helps to overcome these risks. Other benefits of artificial induction are waste reduction and lower production costs.

The practice:

Controlling the timing of natural flowering is a practice that can help companies synchronize flowering, preventing production and harvest scheduling problems caused by changes in climate. The timing of natural flowering varies among countries depending on the climatic conditions, but it affects producing countries in all regions. In Mexico early natural flowering may deliver up to 20 percent of anticipated production, while in Australia it affects 50 to 70 percent of production, and in Brazil, it influences up to 80 percent (Cunha, 2005).

Controlling natural flowering is important for the pineapple sector as early blooming may translate into both revenue reduction due to overproduction at a certain time of the year, leading to market saturation and fall in export prices, as well as in increased production waste. Thus, by controlling production and harvesting conditions, the pineapple industry is better able to favour off-season fruit harvests – when fruit prices are higher –, as well as manage continuous production throughout the year.

Control of natural flowering can be achieved through different methods (Cunha, 2005), including:

- **Planting suckers, slips or crowns** that reach an appropriate size and weight before flowering or at the beginning of the period favourable for natural differentiation.
- **Using planting material** that may go through the period of natural induction without having reached enough vigour to respond to environmental stimuli.
- **Incorporating appropriate management of the crop**, including irrigation practices, to reduce the sensibility of plants to natural flowering stimulants.
- **Using artificial induction** to avoid the effects of climatic factors.
- **Conducting breeding practices** to select desired traits that can make pineapple plants less sensitive to natural flowering stimuli.

Artificial forcing of pineapple flowering (point d above) is a well-established practice in commercial pineapple plantations used to control the timing of flowering and harvest (Espinosa *et al.*, 2016). It ensures that pineapple producers have a continuous flow of fruit throughout the year or in a specific season (Perez, 2019) so that they can deliver high-quality and reliable harvests to their customers in the desired period.

Artificial induction is performed by using ethylene and ethylene releasing chemicals, such as ethephon and acetylene-releasing calcium carbide. Ethylene acts as a hormone to trigger the reproductive phase in the pineapple plant which stimulates the development of the inflorescence when the plant is physiologically mature (Rojas *et al*., 2019). Flowering induction takes place approximately eight to ten months after planting once the plant has reached the desired size for fruit production. The induction can also be performed using naphthalene acetic acid, etherel, ethylene biosynthesis and action inhibitors, such as aviglycine (Espinosa *et al*., 2016; Robin *et al*., 2011).

It is important to note that the use of these products has important implications for producing countries selling to the European Union. A restriction already exists on the use of Ethylene products in European agricultural production, where the product is only allowed for indoor uses. For imports coming from non-EU countries, the maximum residue limit for Ethephon (which releases ethylene gas) on pineapples in Europe is 2 mg per kg, and the chemical is not allowed for use in organic pineapple production. For small-scale companies or producers directed towards export markets, these regulations might make it difficult to find effective alternatives to ethylene or ethephon, as they must carry the costs of researching and sourcing these alternatives, which may not be readily available.

Other options that can be used to manage natural flowering are provided in the list at the beginning of this section. The phytohormones Auxin, gibberellin and cytokinin have the potential to serve as inflorescence initiators, while improving the fruit size and quality of pineapple as noted in a study conducted in the Philippines (Valleser, 2022). These phytohormones may be considered as an alternative for commercial pineapple companies and farmers to produce marketable fruits at a lower cost compared to Ethylene-based products. Producers can consult the European Union's pesticide residue database to access up-to-date information on the maximum residue levels requirements.

4.3 Crop rotation

Climate risks addressed: Droughts, heat stress, changing rainfall patterns, floods, topsoil runoff, frosts, intense rainfall. Other benefits include reduced reliance on external agricultural inputs for nutrient management with resultant production cost savings.

The practice:

The practice consists of producing different crops in the same location (e.g. plot) by alternating these in each cropping cycle. The rotation cycle can be done every year, or every two or three years depending on the number of crops integrated and the growing cycle of each. As mentioned in the section on **integrated pest management** below, by diversifying and sequencing the crops used in the rotation, the incidence of pests and diseases in the cropping system can be managed. Crop rotation also seeks to avoid the exhaustion of the soil that can occur with the continuous production of a single crop (or crops of a single family) (Chaddad, 2016). It is also a key component of conservation agriculture and agroecology.

The rotation sequence is designed so that the requirements for the first crop, in terms of nutrients and water, supplement those of the next crop and so on, allowing maintenance of the soil nutrient balance. A rotation duration of at least two years is recommended to reduce the populations of pathogens, although the presence of host weeds may prevent fully eliminating pathogens (Robin *et al*., 2011). The practice will require producers to pause pineapple production for one cropping cycle or more in one or more plots simultaneously. This may have economic implications, depending on the type of crop used in the rotation system (e.g. non-cash crops).

This technique is particularly relevant for soils that present degradation symptoms and have lost fertility due to the use of synthetic fertilizers, the repeated cultivation of the same crop or the increased intensity of climate events. Some of the key considerations when practicing crop rotation are (FAO, n.d.):

- Always include **cover crops** (also known as green manure) to prioritize the production of biomass that helps in improving the soil cover and organic matter content. The introduction of leguminous plants should be done at least once every two years (InfoAgro, 2022).
- A different species should be sown on the same field in the following season. These species should have different characteristics to those of the pineapple, including the type of vegetation, root system or nutrient needs, among others.
- The selected cover crops should be adapted to the agroclimatic and soil conditions, as well as to the pineapple production system. Thus, the crops to be rotated should result in important benefits for pineapple production.

García-De la Cruz *et al*. (2006), carried out a study in Mexico on the effect of using different legumes in a crop rotation in pineapple plantations. The sowing of legumes (2–3 seeds per blow) was carried out at the beginning of the rainy season and was pruned with a machete four months later when the pineapple was transplanted and without receiving any treatment with pesticides. The results showed that the vigour parameters of the pineapple plants under the rotation system with the *Mucuna deeringiana* legume were higher than those grown in monocropping. It also found increased soil adherence to the roots of the pineapple plants – an indicator of improved soil quality and structure. This was attributed to the activity of endomycorrhizae generated through the introduction of legumes. The productivity of pineapple also benefited, with important economic implications for farmers.
Comparable results were found in Indonesia where pineapple production systems were rotated

with Cavendish banana. The study noted that compared to monocropping or same-species systems, banana rotation improved soil pH and had higher availability of nutrients, such as nitrogen, carbon, phosphorus and potassium (Ramadhani *et al.*, 2021).

In Costa Rica, the use of the leguminous *Mucuna pruriens* was recommended for weed management given the competitive ability of the plant and the low nutrient requirements (Cubero Fernández and Meza, 2014). A study in Mexico also noted that using cover crops such as *Vigna unguiculata* and *Mucuna pruriens* in a rotation system, with a controlled number of herbicides, had a positive effect on weed suppression from 95 to 100 percent (García and García-López, 2021). Moreover, the study found that the use of these crops led to the reduction in herbicides use in pineapple plantations overall. The lower reliance on herbicides will not only minimize production costs, but it will also support environmental protection, sustainability, and resilience of the production system.

It is important to note that using crop rotation may need to be complemented with other nutrient management techniques to maintain the system productivity in the long term. Likewise, producers may need to assess the requirements in terms of labour, equipment and machinery, and seeds needed for the introduction and production of the new crops.

Economic benefits may be achieved through this practice, attributed to higher yields, additional income through additional crops and the redistribution of losses in the event of disease or climate events (Sauca and Urabayen, 2005; Altieri and Nicholls, 2004). Other benefits include the reduction in production costs due to reduced pesticide and fertilizer use.

4.4 Drainage systems

Climate risks addressed: intense rainfall and flooding producing waterlogging with direct impact on the incidence of diseases caused by high soil moisture. If well implemented, the measure can also help prevent soil erosion by preventing topsoil runoff.

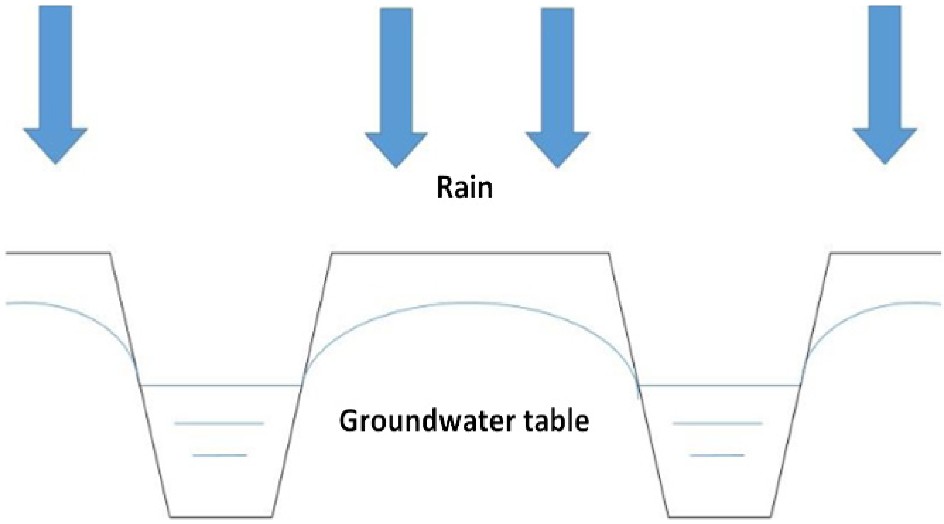
The practice:

Pineapple is intolerant to excessive soil moisture and humidity, making it crucial to design drainage systems that prevent water accumulation in the growing area. Areas at risk of water accumulation, such as low-lying flat lands are not recommended for pineapple cultivation, nor areas with deep slopes (over -2 percent) as they present risks of topsoil runoff. If for any reason these conditions cannot be met, the use of drainage systems is required, and the minimization of the slope must be sought to minimize flooding and topsoil runoff (Esquivel, 2008).

The slope will determine the type of drainage system(s) used as well as the number and distribution of these in the production area. In some cases, there will be a need to implement different systems in the same area. In areas with very irregular slopes, a larger number of drainage channels that are close to each other might be needed to ensure the area is correctly drained. In areas with regular slopes, drainage channels may be more separated because a single system might be able to drain a larger area (Bonet-Pérez *et al.*, 2023).

Surface drainage systems are recommended to remove excess water that may saturate the topsoil due to flooding or waterlogging. These systems eliminate excess "shallow" water and divert it to a natural water stream (Espinosa *et al.*, 2016). Surface drainage works, such as open ditches (**Figure 9**), are especially important at the head of the slope to be able to intercept runoff and reduce the amount of water flowing downstream throughout the slope in the cultivation area.

Figure 9. Surface drainage system by open ditches



Source: **Espinosa, M.R., Carvajal, L.M., Reza García, S.d.l.C., Melo Zipacon, W.F., Bolaños Benavides, M.M., Martínez Reina, A.M., Rodriguez Borray, G., Ospina Parra, C.E. & Abril Castro, J.L.** 2016. Plan de manejo agroclimático integrado del sistema productivo de piña (*Ananas comosus*): municipio de el Peñón departamento de Bolívar (Integrated agroclimatic management plan for the pineapple (*Ananas comosus*) production system: municipality of El Peñón, department of Bolívar). *Boletines de divulgación*. Colombia.

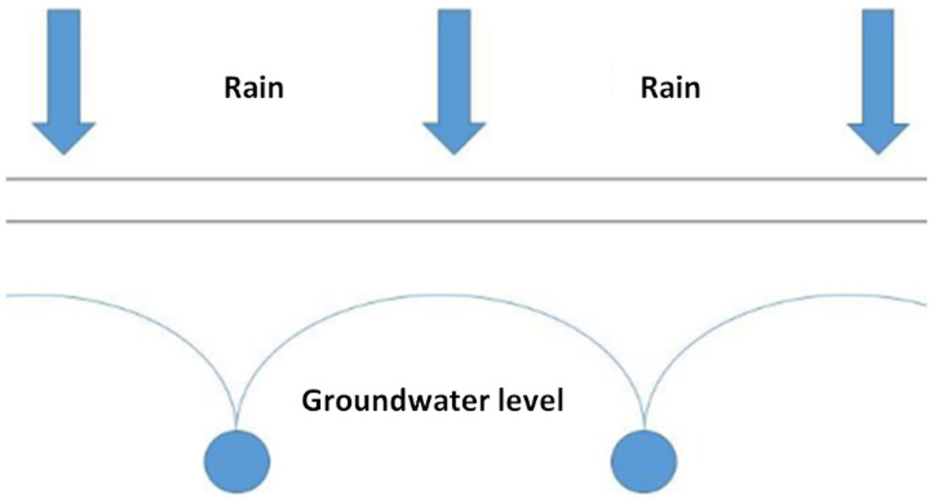
For areas where cultivation takes place in deep slopes, hillside ditches are a recommended surface drainage system. These consist of small channels that are used in areas with heavy rainfall, and with slopes between 10 and 50 percent. Hillside ditches are also built in places where it is not feasible to build terraces of a suitable width for cultivation (Cubero Fernández and Meza, 2014). However, as hillside ditches are implemented in deep slopes, they must be combined with other practices like contour planting,[10] **mulching**, vegetative strips, **living fences and windbreaks** to control erosion.

[10] Contour planting is the practice of tilling and planting following the natural contours in sloped land in order to conserve rainwater and to reduce soil losses from landslides. The practice is an effective measure to minimize soil erosion processes (Cubero Fernández and Meza, 2014).

For the treatment of highly undulating terrain, design should begin from the top down, in order to avoid excessive concentrations of water in channels designed for lower flows (Obando, 2011). Another factor to be considered when defining the channel section is the water flow speed. The flow speed must be fast enough to promote water discharge, and it must also be slow enough to avoid accelerating soil erosion. In any case, this means that it is not recommended to follow a single plan when determining the depth of the drainage channel (Bonet-Pérez *et al.*, 2023), but rather a holistic approach that considers the use of small water diches/reservoirs, slope and water flow and speed.

Sub-surface drainage systems serve to remove the excess water in the cultivation area where the groundwater table is close to the surface causing the saturation of the soil profile and very high moisture content in the root development zone (see **Figure 10**). An example of sub-surface methods are shallow drains, which are sub-surface (tile) drainpipes installed at a depth of 0.5 to 1 m (2.5 to 3 ft). This allows lowering of the water table more quickly after rainfall compared to deep drains, while retaining moisture in the soil and root zone. The systems also improve water quality by reducing nitrate and phosphorus loss by reducing drainage discharge (Ghane, 2022). Some tools such as the Drain Spacing Tool developed by the Michigan State University can help in calculating the depth needed based on drainage discharge requirements.

Figure 10. Sub-surface drainage system using buried drains



Source: **Espinosa, M.R., Carvajal, L.M., Reza García, S.d.l.C., Melo Zipacon, W.F., Bolaños Benavides, M.M., Martínez Reina, A.M., Rodriguez Borray, G., Ospina Parra, C.E. & Abril Castro, J.L.** 2016. Plan de manejo agroclimático integrado del sistema productivo de piña (*Ananas comosus*): municipio de el Peñón departamento de Bolívar (Integrated agroclimatic management plan for the pineapple (*Ananas comosus*) production system: municipality of El Peñón, department of Bolívar). *Boletines de divulgación*. Colombia.

For regions where pineapple is grown on peatlands, drainage systems need to be carefully designed to control the groundwater levels. This will be done by regulating the depth and size of channels and sluice/drain gates (Imanudin *et al.*, 2019). It is recommended that the groundwater level is maintained at 40 to 50 cm below surface to moderate the amount of water needed for crops. This will also prevent the peatland from drying out and reduce soil subsidence, while at the same time ensuring that the land is not too wet for pineapple to grow (*ibid.*). **Figure 11** illustrates a drainage system to regulate water levels in pineapple production in Viet Nam.

Figure 11. Efficient drainage system and water level control is crucial in the cultivation of pineapple in low lying Mekong delta in Viet Nam

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4.5 Early warning systems and monitoring systems

Climate risks and impacts addressed: early warning systems can be used to forecast any kind of climate or other biotic risks, such as pests.

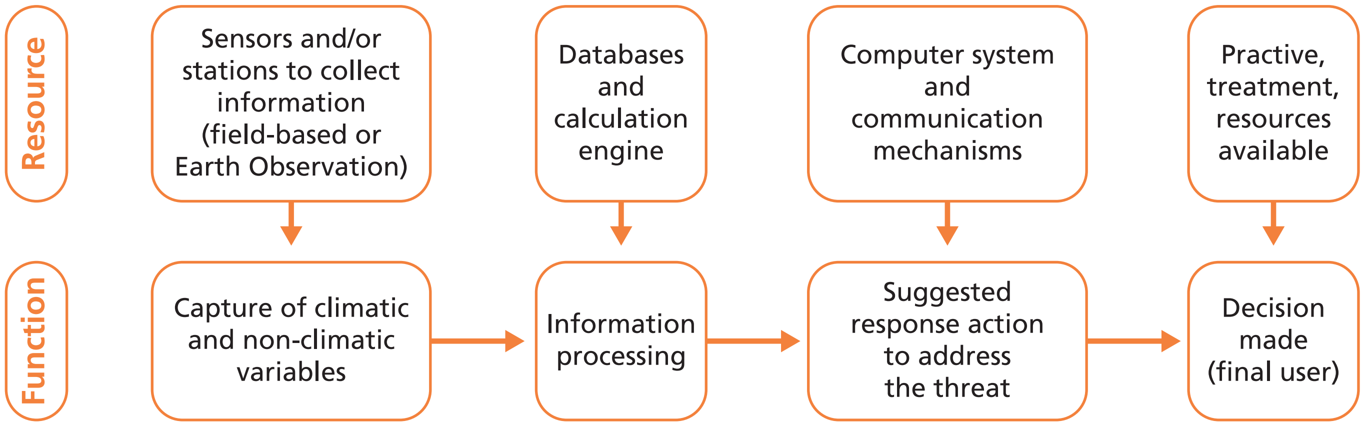
The practice:

Early warning systems (EWS) are a key measure for climate change adaptation. EWS use integrated communication systems that can help producers prepare for expected or unexpected events in a timely manner. EWS can be used for events related to climate or non-climate events, such as pest and disease outbreaks. A successful EWS will allow producers time to protect their production from potential losses, reduce damage to land and infrastructure, and in some instances, save lives. EWS support the long term sustainability and resilience of the production system. To be effective and complete, EWS need to include four key elements (UNDRR and WMO, 2022):

- **Knowledge about the risks that the pineapple production systems face.** This is based on the systematic collection of climate information (e.g. precipitation, temperature and relative humidity, soil conditions etc.) and the assessment of risks in the production system and nearby areas relevant for prediction of intense rainfall or changes in the of onset of the rainy season, among others. Information on the behaviour of markets can and should also be monitored in companies focused on national and international sales. This information may include the evolution of input prices, export prices and exchange rates, among others.
- **Detection, monitoring, analysis and forecasting** of hazards and the potential impacts of these on the production system (crop damage, infrastructure), including other socioeconomic factors (e.g. revenue losses, health hazards).
- **Effective dissemination and communication** of the warning in a timely, accurate and actionable manner. The warning needs to be accompanied with information about the likelihood of the event to materialize and the expected impact.
- **Building response capacity** of producers and other stakeholders engaged to respond to the warning.

Figure 12 illustrates how the information is generated and distributed in an EWS.

Figure 12. Information flow in an early warning system



Source: Adapted from **Pérez Galarce, F.** 2016. Sistemas de alerta temprana para el control de alternaria en tomate. *Villa Alegre*, 338.

EWS can obtain data from different sources, including meteorological stations at the field level, earth observation through geospatial information or traditional forecast methods available in different regions.

Evidence remains limited on the use of EWS in pineapple production. However, studies on other crops have shown the potential benefits of using early detection and warning of climate and non-climate hazards. For instance, an EWS was developed in Malaysia to detect pest attacks on paddy rice. The system was based on a light trap containing a roll of sticky tape, which was placed across specific locations of interest. The light trap was turned on-off at night in ten-minute intervals to attract brown planthoppers from nearby fields. The sticky tape aimed to collect samples on the number of insects in the given field, and a warning would be triggered if the number of planthoppers surpassed a given threshold. Farmers receiving the warning phone message would be also advised to take the necessary actions to manage the pest attack (Bakar *et al*., 2020).

Another example of EWS use is from a project in Zimbabwe, which provided early warning and weather forecast messages to farmers twice a week. The messages coincided with the Meteorological Services Department's three-day forecasting period (FAO, 2022). The messages were delivered through radio or text messages (SMS), providing information on the weather conditions for the following three days. When extreme weather events were forecasted, special messages were broadcasted to allow producers to take anticipatory actions. The results showed that the EWS helped farmers to make important agricultural decisions such as postponing fertilizer application when they received notification that high temperatures and no rain were expected for the following days. Other producers were able to speed up the harvesting of their crops to avoid moisture damage, after receiving a warning of upcoming rains.

In Colombia, a study was conducted to detect how an early-warning systems could be used to identify the risk of avocado wilt complex. A state-of-the-art platform was developed to collect daily data on precipitation, temperature and relative humidity in the environment, as well as the humidity and temperature of the soil. The information gathered was used to predict the likely incidence of wilt based on these variables and produce a warning message for producers and technical advisors via mobile phones. The warning not only intended to prevent damages from the disease, but also to improve real-time monitoring and the design of plantations. The results indicated that the system was able to assess over 70 percent of the temporal factors causing the disease, which allowed producers to take preventive measures (Ramírez Gil, Giraldo Martínez and Morales Osorio, 2018). However, efforts are still needed to improve the accuracy of the predictions to help producers prevent and prepare for future risks and minimize losses in production and revenues.

At the community level, early warning also has important socioeconomic benefits as it allows a better management of seeds, inputs and labour, including planning for seasonal migration (Seydou *et al*., 2023). This might have particularly important implications in pineapple producing areas that depend on domestic or international migrant labour in the production and harvesting seasons.

Early detection of potential adverse effects of biotic and abiotic stresses can also be done through relatively simpler methods. A study in Japan showed that growing a few crops or plants that are particularly sensitive to the given risk, in this case calcium deficiency (tip burn) in lettuce, could act as an early warning system to rescue the main crop where tip burn occurs a few days later. The study mentioned that thanks to early signs of tip burn in the "indicator" crop, calcium fertilization was applied, leading to increasing lettuce yields in a range of 4 to 70 percent (Uno *et al*., 2016).

It is important to note that to develop and sustain an EWS requires strong stakeholder participation from a range of actors including government, research institutions and local communities. Engagement of pineapple producers in the development and design of these systems is crucial to ensure their relevance. Collaboration with research and other public institutions is critical as the amount of data generated by the systems needs to be analysed and processed in order to produce reliable information for decision-making. Early warning messaging also needs to be evaluated regularly and jointly with pineapple producers and associations, to ensure that the information provided is targeted to the needs of producers and that response measures are effectively taken following the receival of information.

4.6 Integrated pest management (IPM)

Climate risks addressed: the practice does not address climate hazards directly, but rather the effects of **increased temperatures** and **humidity**, which in some regions are creating the conditions for new and/or more persistent **pests and diseases**. Co-benefits include the reduction of chemicals, especially highly hazardous pesticides and the associated negative risks to human health and environment.

The practice:

Integrated pest management (IPM) is an agroecological practice that consists of the combination of several agricultural practices –crop rotation and association, mechanical and biological control– to manage pest and diseases. Pathogens that can be managed through IPM include fungi (e.g. *Phytophthora parasitica*, *P. Cinnamoni*, *P. Phythiuin*, *Fusarium*, *Paccelomyces* sp.), insects (e.g. *Dysinicocus brevipes*, *D. Neobrevipes*. *Homóptera-Pseudo coccidae*, *Melanoloma viatrix Hendel*), and weeds that damage the pineapple plants and fruits. Each practice is explained below to address some of the main pathogens identified in **Chapter 3**.

Crop rotation and association

Crop rotation provides pest and disease protection to the production system by removing the potential food sources for pathogens (Robin *et al.*, 2011) by shifting the crops planted every season. More details on the practice, including benefits and some examples of crops that can be used for rotation in pineapple production systems, are offered in the dedicated section on **crop rotation** above.

By rotating out of pineapples, producers can starve the fungal pathogen *Phytophthora nicotianae* causing pineapple heart rot disease and reduce the pathogen levels in the soil (Robin *et al.*, 2011). It is advised that the duration of the rotation be at least two years or more and should be accompanied by other practices including weed management and nutrient management, to effectively reduce the presence of the pathogen in the soil (Loekito *et al.*, 2022). A study in Martinique showed that rotating pineapple with Sunn hemp (*C. juncea*) and controlled grass fallow consistently reduced the presence of *R. reniformis* and *symphylids* by over 80 percent after several rotations (Soler *et al*. 2021). In pineapple plantations, the use of sunn hemp is suitable as a rotational crop rather than an intercropped plant, as the shade it produces might negatively affect pineapple growth in the long term (Wang, Sipes and Schmitt, 2003).

In Indonesia, rotations with banana were found effective to suppress the incidence of Panama disease (*Fusarium oxysporum f.* spp. *cubense*), which affect both banana and pineapple (Loekito *et al*., 2022). Alternating pineapple with other crops, such as cassava and grasses may also reduce the population of *Pratylenchus*, a nematode associated with severe damage to pineapple.

Crop association can also provide protection against pests and diseases by introducing plants that bring in beneficial insects that act as natural predators to pineapple pathogens. These plants could include *Casiatora*, *Desmodum* sp., *Euphorbia hirta*, *Eclipta alba*, *Sida rhombifolia*, *Phyllanthus* sp., *Lanata camara*, *Scleria melaleuca*, *Senna stenocarpoides* and *Solanum* sp. to attract fauna such as *Euplectrus* sp., *Gaediopsis* sp., *Deopalpus* sp., *Colpotrochia* sp., *Brachymeria* sp. and *Cordura* sp. (Quesada-Jiménez, 2013). Likewise, plants that contain bacteria or other features that are able to repel pathogens could be deemed as useful for pest management. An example of these types of plants is the leguminous *Crotalaria* spp., which contains bacteria of the type of *Rhizobium* and *pyrrolizidines* that help pineapple to fend off nematodes (Irmer *et al*., 2015), while fixing nitrogen in the soil.

Biological control methods

These methods refer to practices used to manage diseases by inhibiting plant pathogens, enhancing plant immunity, and/or modifying the environment through the effects of beneficial microorganisms, compounds derived from fungi and bacteria, or healthy cropping systems (He *et al*., 2021). Apart from their use in managing pests and diseases, soil microorganisms have enormous potential for use in agriculture. Some of the benefits include the faster decomposition of organic matter, transformation of nutrients, fixation of nitrogen and other nutrients into the soil. Soil microorganisms can also increase the availability of enzymes and create mutually beneficial biological relationships in the rhizosphere (*mycorrhizae*, *Rhizobium* sp.), leading to the amelioration of contaminated and degraded soils.

There are different methods, products and insects that can help with managing pests and diseases in pineapple plantations in a biological way. Some examples are outlined in **Table 9**.

It is important to highlight that the introduction of certain species or agents for biological control may have undesired effects on the ecosystem, such as threats to local and native species (Teem *et al*., 2020). Therefore, care must be taken when selecting the biological control method to be used to avoid unintended consequences.

Table 9. Biological control methods identified for pineapple pathogens (non-exhaustive)

Pathogen or pest	Biological control method	Country of implementation
***Phytophthora* spp.**	Use of the fungus *Trichoderma* spp. is antagonistic to other fungi and phytopathogenic nematodes. The fungus can also improve the resistance conditions of the plant to pests and diseases, and improves root development.	Costa Rica
Fusarium oxysporum	*Trichoderma* plus *Streptomyces* bacteria can be used as both a preventative and curative method for managing *Fusarium*. The fungal agents can be used in a dose of 12 to 15 L/ha of a dissolution for protection or treatment of the disease. This combination of fungi and bacteria can also facilitate the degradation and sacrifice of infected plants.	Colombia
***Meloidogyne* spp. (nematodes)**	*Paecilomyces lilacinus* is a soil-dwelling fungus that attacks several species of nematodes affecting root health. Its control effect is based on the production of toxic metabolites and parasites that eliminate eggs, larvae and adult nematodes. Formulations usually contain dried *Paecilomyces lilacinus* spore concentrates that are diluted in water and sprayed into the crop to inoculate the plant, and/or is used for treating seedbeds or soils for preparation of seedlings.	Kenya
Pineapple fruit borer (*Strymon megarus*)	Application of biological fungicides such as *B. bassiana* and *M. anisopliae* has been found effective at providing an acceptable level of control of *S. megarus* in pineapple plantations.	Costa Rica
Mealy bugs (*Dysmicoccus brevipes*)	*Rhino Leucophenga* was introduced in Brazil as a predator of pineapple mealy bugs. They are larval predators of scale insects and release eggs or first instar larvae at approximately 2–3 grubs per plant. The use of these was found to be effective in the management of mealy bugs.	Brazil
	Cryptolaemus montrouzieri, commonly called the redheaded ladybird beetle or the mealy bug destroyer. The adult beetle lays eggs in between mealy bug egg masses. The beetle grubs grow up to 1.3 cm (about 0.51 inches) in length and feed on mealy bug eggs and immature crawlers.	India
	Foliar spray of *Verticillium lecanii* or *Beauveria bassiana* at 5 g/ml per litre of water showed to be effective during months of high humidity in reducing the population of mealy bugs.	
	Anagyrus kamali is a parasitoid introduced in Karnataka, India from China to control the pink mealy bugs. It feeds on mealy bug in two ways: the female wasp punctures the bug and sucks the sap and it lays an egg within the bug. When the egg matures, it comes out of the bug's body. The entire process takes only half the entire life span of mealy bugs.	
	The fungi *Metarhizium* spp. is used to combat insects. *Metarhizium anisopliae* has the ability to invade tissues, producing a wide variety of toxic metabolites that harm insects of the order *Coleoptera*, *Homoptera* and *Lepidoptera*.	Costa Rica
Diaspis bromeliae	*Aphytis chrysomphali*, *Aphytis diaspidis*, *Aspidiotiphagus citrinus* (wasps); *Rhyzobius lophanthae*, *Telsimis nitida* (ladybirds); *Dactylopius* sp. can act as natural enemies for the disease.	India
Thecla (*Strymon basilides*)	*Kurstaki* strain of the bacterium *Bacillus* thurigiensis can be used preventively before the development of larvae. The bacteria are applied through water solutions, by spraying the plants where the larvae have been identified. The bacteria act through ingestion by and contact with the larvae.	Costa Rica

Pathogen or pest	Biological control method	Country of implementation
Bacterial rot (*Erwinia* spp.)	*Trichoderma* fungus and/or microorganism decomposers can help control root rot through solutions sprayed on the affected area or as a preventive mechanism to reduce bacteria.	Costa Rica
Elaphria	*Bacillus thuringiensis* works by being in direct contact with the larva. The bacteria are sprayed in a solution (up to four applications of 1kg/ha) directly onto the larvae for effective management of the moth.	Costa Rica
Rotylenchulus reniformis	The endophytic bacteria *Bacillus* sp. was effective at reducing the multiplication of the soil nematode pathogen.	Mauritania
Dickeya zeae	*Bacillus* cereus showed the ability to inhibit the growth of bacterial heart rot pathogen on pineapple variety MD-2 in controlled conditions. Testing at the field level is required to assess the effectiveness of the bacteria in pineapple plantations.	Malaysia

Sources: see the list of references in the end matter.

Box 1 provides an example of the use of biological methods to manage pineapple pathogens by a company in Costa Rica.

Box 1. Example from Nicoverde, a pineapple company using biological control methods in Costa Rica

Company or association: Nicoverde, S.A.
Region: Costa Rica

Increasing temperatures and humidity in the country has increased the incidence and persistence of pests and diseases in pineapple production. Some examples of these are pineapple mealybug (*Dysmicoccus brevipes*) which affects all stages of pineapple growth and can cause total loss of production, and the techla butterfly (*Strymon megarus*) which produces larvae that feeds on the fruit. The presence of these pests not only affects the fruit itself but can also promote the presence of fungi and bacteria in the wounds caused by pests.

More stringent regulations on agrochemical use by importing markets, such as the European Union, has pushed producers to look for more sustainable alternatives for the management of pests and diseases.

In response to the multiple challenges, since 2019, Nicoverde has invested in research and development of biological control methods and crop management with the aim of reducing the load of agrochemicals in the production processes. The company has introduced “trap plants” in the areas surrounding the production zone, which attract pests through their flowers and prevent the pests from entering pineapple plantations. This strategy is reported to reduce the presence of pests and plant diseases in the pineapple plantation, reducing the loss of fruits and plants.

Nicoverde has also been working on the development of new technologies, such as the production and application of microorganisms and fungi on soils to control pests and diseases. Likewise, the company has started testing the use of ozone to disinfect soils where pineapple is cultivated, in order to substitute agrochemicals. The company expects that the incorporation of bioproducts and improved agronomic practices can support the effective management of plant pathogens in a more sustainable way, while improving pineapple productivity, and reducing production costs associated with the use of agrochemicals.

Mechanical methods

These methods refer to any physical or manual control methods, such as hand weeding, and the removal of damaged fruits, leaves or insects (see Figure 13). **Fruit bagging** can be a useful method to prevent the presence and infestation of certain pests such as fruit flies. The use of light blue bags at the flowering stage can avoid oviposition by fruit flies and reduce infestation (Morales Granados and López González, 2001).

To prevent the presence of *Rhyncophorus palmarun L.*, methods such as **removing discarded fruits** from the crop and avoiding leaving overripe fruits in the field can help to reduce the risk of the pathogen. Other ways to protect the fruit include minimizing injuries to the crop, manually removing insects, and using traps and barriers as simple and effective mechanical prevention methods (García Reyes, 1991).

Other simple methods to prevent and reduce pathogens from spreading include keeping **good hygiene** at the production and packing areas. This can be done by thoroughly cleaning machinery and equipment, sanitizing tools, disinfecting seedlings and packing houses, and duly eliminating crop residues and infected plants (García and Rodríguez, 2011).

A key feature of IPM is the regular monitoring of pineapple plantations to detect the presence of pests and diseases early and monitor changes in their levels. Monitoring pathogens should take place throughout the development life cycle of pineapple growth. Monitoring must be accompanied by the correct knowledge and identification of pests, diseases and weeds that may harm pineapple plantations, as well as an understanding of the beneficial plants and insects that could help combat these. Understanding the life cycles and seasonality of pests and disease and invasive species is also required at this step. Plantation history, including pest problems and soil conditions, is a crucial piece of information for IPM in pineapple production as it will allow producers to anticipate infestation. This is a key component for improving the resilience of the production system.

Figure 13. Mechanical weed removal in Kenya

© *FAO/Luis Tato.*

Note that IPM practices may tolerate low pest numbers on plantations and the discrete application of agrochemicals. The latter should be used to address specific pests, diseases or weeds in a measured and targeted way and only when it is necessary (Dreistadt *et al*., 2007). Import market requirements associated with agrochemical use and maximum residue levels (MRL) for exported product must also be taken into consideration before applications of agrochemicals are made. In some instances, IPM practices may not be adequate for the control of certain insects and pests where zero tolerance of these species in orchards is required to meet the phytosanitary requirements of importing countries.

4.7 Intercropping

Climate risks and impacts addressed: droughts, heat stress, soil erosion, soil property loss, weed control, pest control. The practice also contributes to preventing soil losses and the rapid rate of organic matter decomposition/loss in soil, which can result in the decreased productivity of the production system (Cruz *et al*., 2006). Other benefits include control of weeds and diseases, and economic yield from other crops cultivated.

The practice:

Intercropping is the practice of growing crops concurrently on the same field. The practice has several advantages including the reduction of soil erosion, increased production of biomass, and thus, enhanced carbon fixation per area cultivated, pest and disease management, and weed suppression (Mohamadu *et al*., 2009; Ajema and Nigussie, 2021).

Pineapple is a crop that is easily adapted to intercropping systems, given the slow initial growth and the double-row planting system usually used in commercial plantations. Intercropping pineapple with short-cycle crops can enable farmers, including small-scale producers, to sustainably produce pineapple (Siebeneichler *et al*., 2019).

A study conducted in Ethiopia where coffee was used in a strip intercropping system with pineapple at one-to-three ratio, was found to raise the total productivity per unit area. The system also showed benefits on soil improvement and generated additional marketable yield (Ajema and Nigussie, 2021). Another study in the same country found that intercropping haricot bean (*Phaseolus vulgaris*) in between pineapple rows had positive effects on increasing pineapple yield, especially when other practices such as hand weeding and **mulching** were used in the cultivation and management process. Moreover, haricot bean was found to be a useful crop for suppressing the growth of weeds in the field (Eshetu, Tefera and Kebede, 2007). **Figure 14** provides an illustration of a plot where pineapple is intercropped with maize.

Figure 14. Intercropping system of pineapple and maize crop in Mexico

Source: **García de la Cruz, R., García Espinosa, R., Rodríguez Guzmán, M.d.P., González Hernández, H. & Palma López, D.J.** 2006. Efecto de la rotación con leguminosas sobre la productividad del cultivo de piña (*Ananas comosus L. Merr.*) y cultivos intercalados en Tabasco, México. (The effect of rotation with legumes on the productivity of pineapple [*Ananas comosus L. Merr.*] and intercropping in Tabasco, Mexico). Manejo Integrado de Plagas y Agroecología. 77. Costa Rica.

Generally, pineapple is a good intercrop during the first two to three years establishment of perennials such as oil palm, rubber, coffee, coconut and fruit crops. The practice helps to optimize land use by taking advantage of the space before the full canopy development of trees. Research from Malaysia showed that intercropping of banana and pineapple with immature-rubber is more productive than growing the crops as monocultures (Mohamadu *et al*., 2009). However, the study also noted that as rubber grows, the competition for resources among crops, as well as the increased shade brought by the canopy, might decrease banana and potentially pineapple productivity in the long term. Thus, the careful selection of the species to be used as intercrops and the design of the planting systems (e.g. one row of rubber trees to three rows of pineapple or banana) is required to address the potential negative effects.

A study in Brazil, showed that an intercropping system with pineapple and rice is viable for pineapple production at different scales (Siebeneichler *et al*., 2019). Pineapple-rice intercropping showed a slight increase in pineapple yields and did not affect the fruit mass nor the quality of the pineapple produced. Likewise, no competition for light or soil nutrients in the initial pineapple development phase was observed. The experiment also tested intercropping with two rows of cowpea (*Vigna unguiculata*), which did not provide good results for pineapple production as it reduced yields, probably explained by competition with the main crop. To overcome these effects, the researchers suggest using a single row of cowpea between the double row of pineapple.

Intercropping can also play a key role in enhancing the economic resilience of pineapple production systems. The cultivation of two or more crops can provide additional income sources to producers and buffer against potential losses in revenue if market or climate shocks are experienced.

4.8 Integrated management of agricultural water resources

Climate risks and impacts addressed: drought, intense rains, changes in rainfall patterns and soil erosion. Other benefits include reduction in the use of external inputs, such as fuel in irrigation systems, and agrochemicals. Social benefits include improved water availability for household use and production.

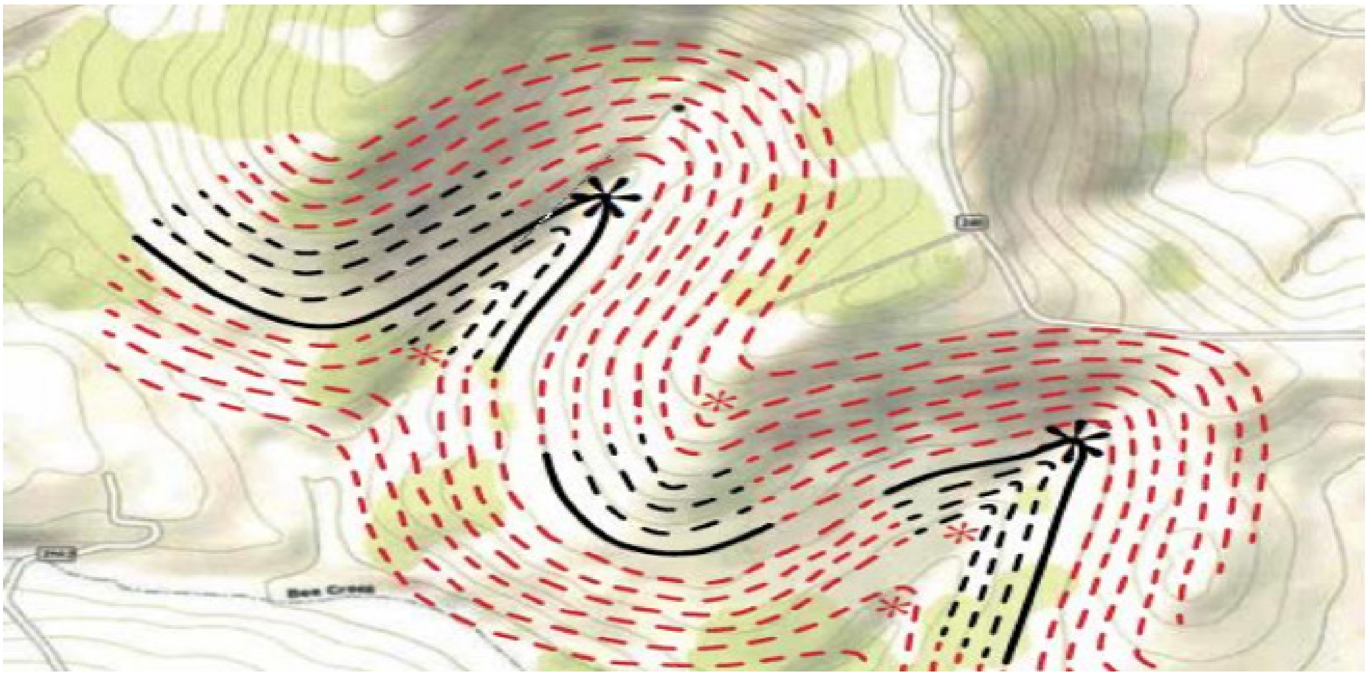
The practice:

Integrated management of agricultural water resources is a process that promotes the coordinated development and management of water, land and related resources to maximize the efficiency in water consumption and protect ecosystems. The practice has important agricultural water-saving potential by combining agricultural techniques, infrastructure investments and water-saving techniques (Zhang and Guo, 2016).

An example of integrated water management is contour planting, mainly **keyline design** (see **Figure 15**). The practice consists of a combination of methods for water conservation and regeneration of soils. The system is composed of planting lines and channels created in the soil by using minimum tillage practices, aiming to improve water infiltration, aeration, reduce water erosion and stimulate root growth (Bessert, 2022). Keyline design can be divided in two types: a) keyline ploughing which creates parallel cultivation lines following the special geographical features to guide the water flow up to higher elevations instead of gathering in the valleys; and b) the combination of grazing and tree rows, or to cultivate hillslopes through terracing (Johansson, Brogaard and Brodin, 2022).

The practice seeks to establish reference contour lines that do not result in a cultivation pattern that is too steep and thus does not enable water erosion. The objectives of keyline planting include shielding the soils against the effects of drought or intense rains; distributing water evenly; and converting the soils into large water stores and carbon sinks. The practice is one of the most effective conservation agriculture practices that helps to retain soil, increase water infiltration, and keep the water uniformly in the land to recover or maintain its fertility (del Carmen Ponce-Rodríguez *et al.*, 2021). It is important to note that the practice does not only help to address water risks related to deficit, but is also effective for draining excess water, the latter being particularly relevant to the pineapple sector in different producing regions.

Figure 15. Keyline design as an example of for integrated water management in agriculture



Source: **Bessert, L.** 2022. *Keyline Design- water management of agricultural landscapes: Key for Regenerative agriculture?* University of Kassel. https://agroforst-info.de/wp-content/uploads/2023/01/bessert-Keyline_angepasst.pdf

Agroforestry systems are especially suitable for the implementation of Keyline design (see section on **agroforestry** for pineapple production). In these systems, pineapple and tree species are planted along the swales on the descending site. Thereby, the water availability for tree roots is improved particularly on steeper slopes, while soil erosion is prevented (Gerhardt, 2021). The practice can guide the design of cultivation patterns in specific production sites, but can also be used to redesign whole landscapes, making these more resilient to climate change and impacts.

Overall, integrated agricultural water management include practices such as (FAO, n.d.):

- Rainwater harvesting, **soil** and **water conservation**, deficit and supplementary irrigation use, among others, in order to increase the availability of water available to crops.
- On-farm water management to minimize water losses by evaporation (e.g. use **mulching and cover crops**, **windbreaks**).
- Use of crop varieties resistant to droughts and high humidity.
- Use of improved cropping systems and agronomic practices, such as minimum tillage or key line ploughing.
- Use of non-conventional water (e.g. harvested rainwater or treated wastewater) in non-agricultural activities, such as cleansing machinery and equipment.
- Evaluation of rainfall patterns to determine quantity and quality available for agriculture use and design crop system, particularly in pineapple production systems that grow in combination of other crops (**agroforestry**, **intercropping systems**, **cover crops**). Monitoring rainfall also helps in the decision-making of specific processes such as the timing in the application of fertilizers and pesticides.

When taking an integrated approach to manage agricultural water it is important to know the soil properties and crop water needs, as this will shape which agronomic practices and other infrastructure work might be needed.

Before adoption, it is important to identify the environmental impacts related to the implementation of infrastructure as it might generate risks to local ecosystems. For instance, when harvesting and storing water, the amount of time in which water will be stored, the content of organic matter present and the potential for other fertilizers to be transported through runoff should be considered. Exposing stored water to solar radiation exposure may also affect the water properties with potentially negative effects on soil and ecosystems when using the water for agriculture or other uses.

Box 2 highlights an example of irrigation systems and other soil management practices implemented by ASOPROPIMOPLA in the Dominican Republic to address increasing rainfall and associated flooding events linked to climate change.

Box 2. Drainage systems and soil management practices used by ASOPROPIMOPLA in the Dominican Republic

Company or association: Asociación de Productores de Piña de Monte Plata (ASOPROPIMOPLA)
Region: The Dominican Republic

Increasing rainfall over the past decade has had a negative impact on pineapple production in the Dominican Republic. The increased humidity, waterlogging and soil erosion associated with these climatic events has reduced the feasibility of pineapple cultivation and productivity.

In response to these impacts, the association started to implement soil modification practices to improve drainage to quickly evacuate excess water generated by rains in and around the productive area. The association has also established living fences and perimeter walls to reduce the speed of the water entering the plantation and to allow for better water infiltration into the soil, while avoiding water accumulation/stagnation in a single point.

The association has also taken measures to improve soil preparation before sowing to promote soil stabilization. For instance, pineapple plants are placed in the middle of the furrow to ensure uniformity in the cultivation, and therefore avoid soil movements, especially when heavy rains occur. Together with the perimeter walls, this measure has prevented the incidence of clogged drains and loss of pineapple plants placed outside the furrows after heavy rains.

The combination of drainage systems and soil management practices are reported to have positively contributed to reducing the loss of plants and crops, as well as reducing the incidence of diseases in pineapple plantations due to excess water and humidity in the cultivation areas. The Association indicates that the latter has allowed the maintenance of the quality and safety of the pineapples produced.

Since implementation of these adaptation practices began, the Association reports that fruit losses have been reduced and the production of export-quality pineapples has improved.

4.9 Mulching and cover crops

Climate impacts addressed: soil erosion from intense rainfall and wind, low humidity, competition with weeds for nutrient uptake. Permanent soil cover can also protect suckers and roots from **frost, drought, changes in rainfall patterns and sudden temperature changes**. Other beneficial impacts include improving soil structure and fertility and reducing pest incidence by interrupting the pest cycle through adding other crops. Together, these benefits can reduce the need for agricultural inputs such as fertilizers and pesticides.

The practice:

Mulching and cover crops are conservation practices used to regenerate and protect the soil structure and health (Oloo *et al.*, 2013).

Cover crops, also known as green manure, are considered a good soil conservation practice in pineapple production with the potential to increase the sustainability of the system. The use of green manure reduces soil erosion and ameliorates soil physical properties by increasing soil organic matter, fertility levels and nutrient retention (Wutke *et al.*, 2009). This is because cover crops are normally incorporated back into the soil, either directly, or after removal and composting. It has been estimated that plants cultivated after cover crops can use up to 40 percent of the nitrogen fixed by cover crops (*ibid.*). Some recommended cover crops to be used in pineapple systems include velvet bean (*Mucuna deeringiana*), castor (*Ricinus communis*), sword bean (*Cannavalia ensiformis*), and 'Abruzzi' rye (*Secale sereale*) (Wang *et al.*, 2003).

The selection of cover crops to cultivate with pineapple needs careful deliberation to avoid potential weed invasion or attracting diseases that may affect pineapple production. **Native and local species should be prioritized to mitigate potential negative ecological impacts.** Selective cover crops such as legumes can be important sources of nutrients for the soil, helping with nitrogen fixation and other nutrients by the rhizobia bacteria in the soil that creates symbiosis with the root (Cubero Fernández and Meza, 2014) . By improving nitrogen fixation and soil structure overall, the use of fertilizers can be reduced contributing to climate mitigation.

Soil mulching also offers protection to soils by using organic or inorganic material. The practice helps to manage the soil moisture, offers protection against increasing temperatures and radiation. Mulches also reduce soil erosion by preventing leaching and washing away of nutrients by heavy rainfall or irrigation (Palencia Ortega, 2016) and can offer protection to crops against damage caused by birds (Prakash and Meherda, 2022).

Organic mulching is composed of vegetative matter or other crushed material (e.g. crop residues including crowns, fruits and stubble, straw, cut grass or leaves, **Figure 16**) spread over the soil surface as a loose layer of organic material.

Figure 16. Example of agricultural waste from pineapple plants to be used for mulching

Source: **Hernández-Chaverri, R. & Prado Barragán, L.** 2018. Impacto y oportunidades de biorrefinería de los desechos agrícolas del cultivo de piña (*Ananas comosus*) en Costa Rica (Impact and biorefinery opportunities of agricultural waste from pineapple [*Ananas comosus*] cultivation in Costa Rica). *UNED Research Journal*, 10: 455–468.

The use of organic agricultural waste as organic mulch not only improves soil organic content but can also have important climate change mitigation potential by reducing waste and stimulating carbon storage.

Dry leaves are widely used in forest areas and where trees are abundant, and for pineapple plantations established near forests or when grown in agroforestry systems. Composted leaves or small branches and wood barks can be combined with dry leaves to improve the quality of the mulch and reduce the loss of dry leaves when wind is present (Ranjan *et al*., 2017). Straw is also a good mulching material as it provides insulation and water penetration. The use of organic mulch ameliorates soil physical properties and reduces soil erosion by adding organic content and increasing nutrient retention.

Synthetic or inorganic mulches are formed by materials, such as plastic sheets or rocks, that cannot be degraded by soil organisms (see **Figure 17**). Plastic mulches reduce evaporation by regulating the vapor flow between soil surface and atmosphere. Black polythene or silver shine plastic mulch have shown to improve the soil pH, reduce nutrient leaching and preserve moisture. A study in Nagaland, India showed that pineapple fields that were covered with plastic mulch had higher basal respiration, soil microbial biomass carbon[11] and soil moisture than fields with no mulches (Sangma *et al*., 2019).

[11] Microbial biomass carbon is a measure of the carbon contained within the living component of soil organic matter (i.e. bacteria and fungi).

Although these measures are more long-lasting than organic mulches, the main disadvantage of plastic mulch is the cost of the material, lack of biodegradability and difficulties in collecting and disposing of plastic after use. The latter may also have negative ecosystem impacts related to plastic waste and pollution if not carefully managed.

Figure 17. Use of plastic mulch and cover crops in a pineapple plantation in Ghana

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Another important effect of plastic mulching is the reduction of weeds in the field, a major problem in pineapple cultivation (Tivelli and Purquerio, 2012). A study from Ethiopia showed that combining mulching with hand-weed control measures not only helped to eliminate weeds fully, but also doubled pineapple yields compared to plots where only hand-weeding took place (Eshetu, Tefera, and Kebede, 2007). Similar results were observed in India where plastic mulch eliminated the presence of weeds in the field (Sangma *et al*., 2019). Mulching with plastic can be useful for weed control in commercial pineapple fields because it is a more cost-effective measure than manual or herbicide operations. However, the use of organic mulch and cover crops are a more sustainable alternative to be used in agricultural production systems (Robin *et al*., 2011).

Lastly, the use of mulch can promote a reduction in the total water consumption, and subsequently water footprint (blue and green water footprint) of pineapple plantations. A study in Costa Rica showed that mulch could reduce the water footprint by 18 percent compared to conventional pineapple production in which the practice is not used (Sirika, 2011).

Figure 18. Tractor with modified equipment used to lay silver shine plastic mulch for pineapple cultivation in Malaysia

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It is important to note that other problems causing deterioration in soil quality also need addressing. For instance, soil compaction can be caused due to the use of heavy equipment for soil preparation; increased salinization can occur due to excess water extracted for irrigation; and soil pollution may be attributed to the intensive use of agrochemicals. An example of the use modified equipment to minimize soil compaction during the laying of plastic mulch on pineapple plantations is presented in **Figure 18**.

Box 3 presents an example from a company in Costa Rica that is taking an integrated approach to managing natural resources, including the use of cover crops, water management and reduction of agrochemical use, to restore soil health and protect ecosystems.

Box 3. Example of an integrated approach of soil and natural resources management in Costa Rica

Company or association: Fyffes
Region: Costa Rica

Soil degradation, the loss of biodiversity and ecosystems pose a major threat to the resilience of the pineapple industry facing climate change. In response, Fyffes launched soil conservation programmes in Central America to help mitigate the effects of soil loss and preserve natural resources and biodiversity. These programmes uses integrated management through the implementation of natural vegetation cover, as well as the use of containment zones near drainage ditches on pineapple and banana farms in Costa Rica, Ecuador and Belize. Similarly, Fyffes has adopted integrated pest management, reducing the use of herbicides in pineapple and banana production. Together, these have led to a decrease in the runoff of agrochemicals applied on the farm, especially after heavy rains.

With the use of these integrated practices, Fyffes reports increasing the efficiency of pineapple production and reducing the use of inputs. It further reports that this has made it possible to protect, restore, maintain and improve the natural fertility of soil and ecosystems, and to decrease in the use of agrochemicals, which has reduced the risk to workers' health.

4.10 Solar protectors

Climate impacts addressed: heat stress, solar radiation, hail, frost, cold stress and strong winds. Other benefits include **protection against flying pests** (insects, birds, bats), increased production of higher-quality fruit and marketable yields. The reduction of post-harvest waste also has important climate change mitigation potential, and overall benefits of shade nets may increase system resilience.

The practice:

Pineapples are susceptible to heat stress and sun damage, which can significantly reduce yield and fruit quality as discussed in **Chapter 3**. However, several chemical measures (e.g. vegetable oil, kaolin, silicon and wax-based products) or physical methods (e.g. use of Saran, shades, plastic bags, or paper) can offer protection against high temperatures and increasing solar radiation (Peña, 2018). **Vegetable oil**, formulated with organic ingredients including oxygenated glycerol and fatty acids from oil palm, can act as sunscreen protection to pineapple. Other mineral based oils made from kaolin can also be used. In addition, the oils can offer other benefits to fruits, by repelling fugal pathogens and some insects like mites, reducing rot-related losses and delaying ripening (Peña, 2018).

Vegetable oils are usually sprayed directly onto fruits to form a protective film. A study from Costa Rica showed that the use of vegetable oil (4 L/ha on plantations, and 60mm/L in post-harvest management), had positive effects in reducing the temperature of the crop canopy, thermic stress and lowering the extent and severity sunburn damage by 90 percent (Peña, 2018). Another study showed similar results where the use of vegetable oils delivered effective sun protection to over 94 percent of pineapples (Ramírez-Espinoza, 2007). Sunburn injury was also lower when compared to commercial treatments composed of minerals such as aluminium silicate, kaolinite and dimenthene used in the sector. The use of vegetable oil also yielded positive effects of increased foliar emission rate[12] before floral induction and was associated with larger fruit size (*ibid.*). However, compared to other commercial treatments, the acidity levels presented in the fruits treated with vegetable oil were slightly higher. Yet the levels were still within the thresholds required by international markets.

The use of **Saran** (made of black polyvinyl chloride (PVC)) placed around the entire plant and fruit was found to provide strong protection to MD-2 pineapple compared to other methods. A study showed that black Saran at 30 percent managed to reduce the rate of damaged fruits down to only 0.3 percent of the total production compared to other physical or chemical methods (Ramírez-Espinoza, 2007). This method was also found to be effective in maintaining the internal temperature of the fruit closer to that of the environment, thus reducing internal damage associated with heat and preserving quality even after fruit harvesting.

Shade nets can also protect pineapples from direct sun in the production and post-harvest phase. The use of shade nets and Saran can further help to protect pineapple plantations against cold stress and frost, especially during the early development of the plants. However, it is important to note that pineapple growing under a shade net may present slight alterations in quality, as the fruits tended to be slightly more acidic and juicier (Gamboa, 2006). **Figure 19** shows examples of different shade nets to provide protection to pineapple in the field and at the post-harvest stage.

[12] This refers to higher production of leaves by the plant and thus, better photosynthetic and nutrient uptake.

Figure 19. Use of different shade nets to protect pineapple from direct sun

Note: Left picture shows a pineapple protected by black Saran. Right picture shows black shade net protecting harvested pineapple in Costa Rica.

Sources: Left picture: **Ramírez-Espinoza, F.** 2007. Efectividad de siete métodos de protección de la fruta de piña contra los rayos solares (Ananas comosus)(L.) Merr. híbrido MD-2. Right picture © FAO/Ezequiel Becerra.

The use of **reusable plastic covers** on top of the pineapple fruit can also protect production from sun scorching as solar radiation increases (see **Figure 20**). This can also constitute a more sustainable strategy compared to the use of single-use plastics or other unrecyclable materials.

Figure 20. Reusable, plastic covers are used to prevent sun scorch on MD-2 pineapples in Malaysia

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Fruit bagging consists of using plastic or paper bags to prevent sunburn. The use of bags has shown good performance in protecting crops and reducing sunburn damage (by up to 7.9 percent when covering with plastic bags and 8.3 percent when covered with paper bags) compared to unprotected fruits (18 percent of damage). Fruit bagging also reduced the intensity of the damage (Ramírez-Espinoza, 2007). A study conducted in China showed that the use of expanded polyethylene (EPE) bags showed positive effects on fruit quality, improving texture, nutritional content and skin protection (Zhang *et al*., 2022). An advantage of EPE and paper bags is that these are recyclable or can be made of biodegradable materials. This can potentially reduce agricultural waste and promote more sustainable pineapple production compared to single-use plastic bags (Zhang *et al*., 2022). However, it is important to note that the use of bags can contribute to increasing the internal fruit temperature (Omar, 2014) and therefore their use should be carefully monitored to prevent internal damage from occurring.

A widely used, low-cost technique for sunburn protection is **tying pineapple leaves** on top of the young pineapple fruits, which avoids the direct impact of sun. However, as with shading, wrapping pineapples could lead to a reduction in the fruit size and sugar content (Zhang *et al*., 2022).

Pineapple production systems can also be protected from sun and radiation by **natural shade from surrounding forests or trees or by trees grown in agroforestry systems** (see corresponding section and **Figure 21** for a visual example of these systems). Pineapple that grows within a heterogenous agroecosystem with the presence of trees and shrubs can act as a "buffer" to rising temperatures and radiation changes, as well as to other changes in the environment (Espinosa *et al*., 2016).

Figure 21. Pineapple productive system under natural shade in western Mexico

Source: **Rosales Adame, J.J., Cuevas Guzmán, R., Gliessman, S.R. & Benz, B.F.** 2014. Estructura y diversidad arbórea en el sistema agroforestal de piña bajo sombra en el occidente de México. (Tree structure and diversity in a shade pineapple agroforestry system in western Mexico). *Tropical and Subtropical Agroecosystems*, 17(1): 1–18.

Other agronomic methods used to provide sun and radiation protection to pineapple include using **mulch** through the application of dry grass on the soil and on the pineapple, and keeping the plant foliage upright by using ropes (Adabe, Hind and Maïga, 2016). Likewise, **intercropping** and the use of **cover crops** in pineapple plantations can help to protect fruits from sunburn and heat stress as dry, bare soils are likely to reflect more sunlight into the orchard canopy than those covered with green vegetation (Lal and Sahu, 2017).

4.11 Waste management

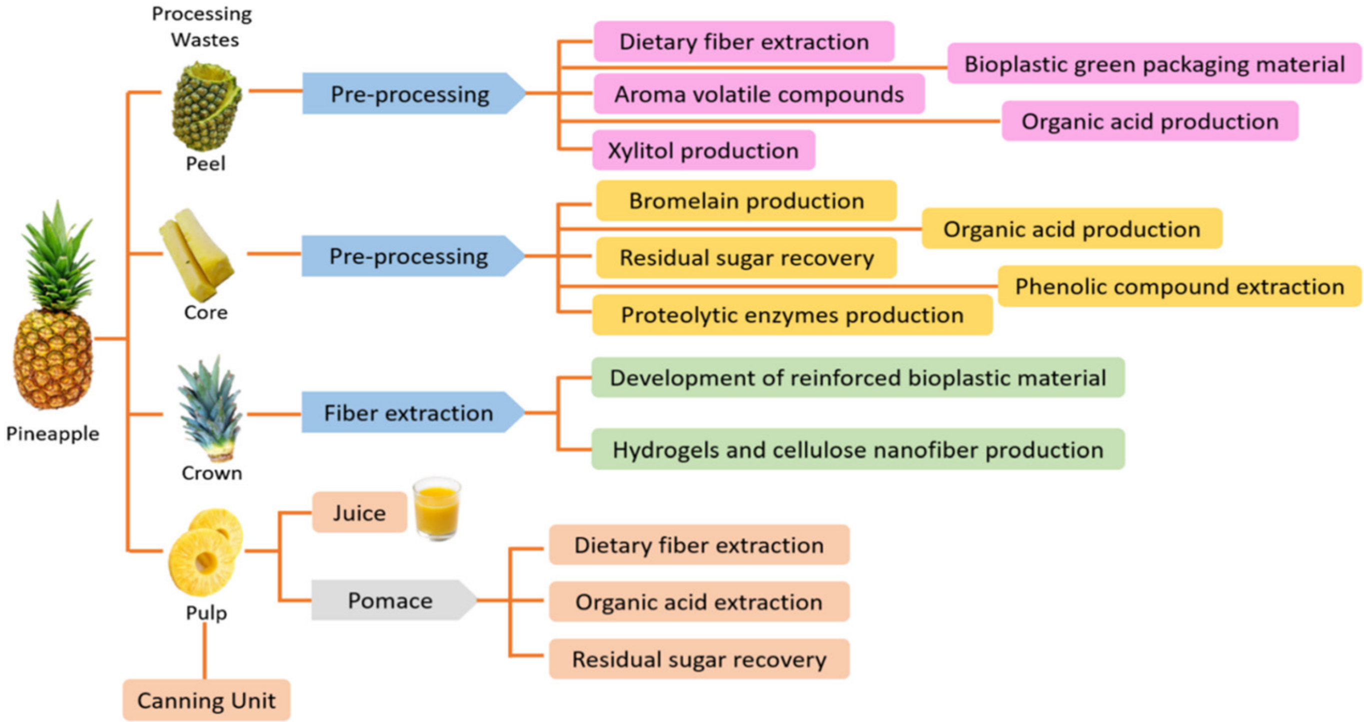
Climate impacts addressed: the practice does not respond to specific climate hazards. Instead, waste management aims to reduce the impact generated by the industry caused by agricultural residues and discarded material. This has important climate mitigation potential. Other benefits include economic gains through the commercialization of by-products (e.g. biofertilizers, handcrafts, and biofuel) and reduction of production costs.

The practice:

Waste from industrialized pineapple production can have potential uses as a raw material for obtaining value-added products through processing. Pineapple waste contains simple and complex sugars that may be used in fermentation to produce different metabolites such as ethanol, citric acid or vinegar. Pineapple residues also contain the proteolytic enzyme bromelain, commonly obtained from the stem, which can be used in pharmaceutical and food industries, as well as in the cosmetics, textile, leather and detergents industries (Gil and Maupoey, 2018).

Figure 22 outlines the products that can be extracted from different fruit parts and agricultural residues and **Table 10** lists some products that can be extracted from pineapple residues. **Figure 23** presents an example of sandals made from pineapple fibre in the Dominican Republic.

Figure 22. Pineapple by-products extracted from different fruit parts



Source: **Van Tran, T., Nguyen, D., Nguyen, T., Nguyen, D. , Alhassan, M., Jalil, A., *et al.*** 2023. A critical review on pineapple (Ananas comosus) wastes for water treatment, challenges and future prospects towards circular economy. *Science of the total environment*. 856 (1). https://doi.org/10.1016/j.scitotenv.2022.158817

Table 10. By-products derived from pineapple residues (non-exhaustive)

By-product	Observations
Furan compounds	Furan compounds were deemed an environmentally friendly option to work as an oxygenate additive or as a technological solvent material and an alternative to MTBE (Methyl tertiary-butyl ether).
Bioethanol and bromelain	Simultaneous saccharification and fermentation (SSF) using cellulolytic enzyme and yeast was used for the production of bioethanol from pineapple leaf waste. SSF can also support the extraction of bromelain, which can be used in the cosmetic industry.
Biogas	Fresh pineapple stubble can be used to produce biogas. It is estimated that one kilogram of stubble can render 25.7 litres of methane.
Paper	Pineapple leaves can be pulped to create fibre and transformed into paper. Pineapple-based paper has been found to be highly absorbent and durable.
Biomanure	Processed pineapple residues used in the production of bioethanol can be first inoculated and then enriched with nitrogen, phosphorus and potassium using *Fischerella muscicola*. This will allow use of the residues as biofertilizer.
Food industry	Starch: Extracted from pineapple waste, especially from stem waste, using a milling process. Isolated high purity starch can be used as an alternative to starch obtained from rice, corn and cassava. Dietary fibre: Pineapple peel contains insoluble rich fibre segments that can be used in producing low-calorie, high-fibre foods. Vinegar production: Simultaneous fermentation with Acetobacter can transform pineapple peel to vinegar. The resulting vinegar was found to have phytochemical and antioxidant properties.
Textile industry	The stubble, being a natural vegetable fibre, adheres to other types of fibres, whether natural or even synthetic, for the generation of a textile.

Source: Adapted from **Hernández-Chaverri, R. & Prado Barragán, L.** 2018. Impacto y oportunidades de biorrefinería de los desechos agrícolas del cultivo de piña (Ananas comosus) en Costa Rica. *UNED Research Journal*, 10: 455–468. See the list of references in the end matter.

Figure 23. Sandals made from pineapple residues by ASOPROPIMOPLA in the Dominican Republic

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It is important to consider that many of these processes may require high investments for processing, as well as collaboration with other actors (e.g. government and research institutions) and stakeholders (e.g. biofuel or cosmetic industries). Also, their environmental and socioeconomic impact, carbon footprint and life cycle of the by-products generated should be assessed to ensure their sustainability (Hernández-Chaverri and Prado-Barragán, 2018).

4.12 Windbreaks and living fences

Climate risks and impacts addressed: strong and frequent winds. The practices have the potential to reduce the effects of **drought, extreme heat** and even **frost** as the planted trees also create a microclimate. Windbreaks also prevent **wind and water erosion**.

The practice:

Windbreaks and **living fences** consist of planting rows of high-density trees and shrubs of different heights (short, medium and tall) to protect the crops from strong wind (Obando, 2011; see **Figure 24**) and to reduce water velocity and force sedimentation (Fernandez *et al.*, 2013). Thus, these practices contribute to limiting wind and water erosion and are considered an important tool in the implementation of climate-smart agriculture and agroecology strategies. The reduction of strong wind could also be reflected in improved fruit quality due to the lower incidence of wind scarring and thus a reduction of the potential for pathogens that can enter the fruits through these scars (Holmes and Farrell, 1993).

Windbreaks can act as living fences and vice versa. Living fences are usually planted along the outer periphery of the land, for instance, on level curves and forming a continuous barrier with the objective to control erosion. Windbreaks on the other hand, can also be planted internally.

When establishing the trees and shrubs, it is recommended to place them at the top of primary and secondary drainage channels to reduce erosion and avoid runoff of pesticides and fertilizers into drainage channels (FAO, 2011). To enable these functions, the implementation of densely growing bushy plants, with small roots is advised.

Figure 24. Design of living fences or windbreaks combining trees and bushes

Source: **Amaya Román, G. & Sánchez Rincón, J. S.** 2022. *Propuesta de implementación de herramientas de manejo del paisaje como aporte al desarrollo rural sostenible en una finca productora de piña (Ananas comosus) del municipio de Monterrey, Casanare* (Proposal for the implementation of landscape management tools as a contribution to sustainable rural development in a pineapple [*Ananas comosus*] producing farm in the municipality of Monterrey, Casanare). Universidad El Bosque. Colombia.

Windbreaks and living fences also help to regulate climate conditions in the production area (Singh, 2023). They are particularly suitable in areas with low precipitation and where high temperatures are being experienced, as the presence of trees and shrubs help to preserve the humidity and moderate temperature in the plots. The practices also provide other ecosystem services such as landscape improvement or restoration, biodiversity protection or serve as biological corridors for insects and animals (Weninger *et al*., 2021). The implementation of these measures has potential to support climate mitigation efforts, as the increased biomass present in the production system can promote carbon sequestration and storage.

The establishment of living fences adjacent to a stream, lake, or wetland as well as the productive area, can also act as **forest buffers**. Forest buffers provide food and cover for wildlife, improve water availability, regulate water and environmental temperatures and slows out-of-bank flood flows. Thus, acting as natural shelters for local biodiversity and as a line of defence against extreme weather events. **Figure 25** presents a visual example of the use of grasses along drainage channels.

Figure 25. Use of vetiver (*Chrysopogon zizanioides*) as living fence in the drainage channels

Source: Ministerio de Agricultura y Ganadería de Costa Rica (2019)

Considerations for implementation include the selection of tree and shrub species that do not imply high competition with pineapple production. It is recommended that the selected species are fast and upright growing, with perennial foliage and that are not known hosts to pests and diseases affecting pineapple. Tree and shrub species should also be flexible and respond well to pruning. Some recommended plants are included in **Table 11**.

It is advised that native and local species are incorporated as part of windbreaks to protect local biodiversity and prevent the risk of invasion of non-native species. Soil properties and water availability is critical to ensure the maximum survival and performance of planted species.

Table 11. Recommended species for living fences or windbreaks for pineapple plantations (non-exhaustive)

Species	Main characteristic	Other uses
Vetiver *(Chrysopogon zizanioides)*	Fast-growing bush	Medicinal
Lemon grass *(Cymbopogom citratus)*	Fast-growing bush	Human food, medicinal
Purple coral tree *(Erythrina fusca)*	Slow-growing tree	Animal food, timber, ornamental
Cochlospermum orinocense	Fast-growing tree	Timber (handcraft and joinery), medicinal, ornamental
Rubber tree or rubber plant *(Hevea brasiliensis)*	Economic co-benefits	Timber, wildlife food, resin
Matarratón or cacahuananche *(Gliricidia sepium)*	Fast-growing tree	Livestock and wildlife food, pest management
Teak *(Tectona grandis)*	Economic co-benefits	Timber (handcraft)
Jobo *(Spondias mombin l.)*	Slow-growing tree	Food (Human, wildlife, livestock), timber (handicraft, construction), medicinal, shade
Strangler fig *(Ficus donell-smithii)*	Pollinators' attractant	Food (wildlife), timber (construction), medicinal, resin, shade
Baluster *(Ochroma pyramidale)*	Fast-growing tree	Timber (handicraft, construction and joinery)
Hawthorn *(Crataegus)*	Fast-growing tree	Timber (artisanal and construction)
Pochote *(Bombacopsis quinata or Bombacopsis quinata)*	Endangered species recommended for conservation purposes	Timber (handicraft, construction and joinery)
Guáimaro tree *(Brosimum alicastrum)*	Endangered species recommended for conservation purposes	Livestock and wildlife food, artisan timber and construction, ornamental
Blackberry *(Rubus)*	Fast-growing bush	Human and wildlife food, dying material, medicinal
Pavito *(Jacaranda copaia)*	Fast-growing tree	Timber (handicraft and joinery), ornamental
Pink poui or rosy trumpet tree *(Tabebuia rosea)*	Slow-growing tree	Agroforestry and silvopastoral systems, ornamental
Mamica de cadela, tambataru and prickly ash *(Zanthoxylum rhoifolium)*	Fast-growing tree	Timber (Handicraft and joinery), dying material
Varasanta or ant tree *(Triplaris americana)*	Fast-growing tree	Timber (construction), firewood
Trumpet-tree or Yarumo *(Cecropia peltata)*	Fast-growing tree	Timber (handcraft), ornamental

Source: Adapted from **Amaya Román, G. & Sánchez Rincón, J. S.** 2022. *Propuesta de implementación de herramientas de manejo del paisaje como aporte al desarrollo rural sostenible en una finca productora de piña (Ananas comosus) del municipio de Monterrey, Casanare*. Universidad El Bosque. Colombia.

Box 4 provides an example of a company in Costa Rica that has incorporated living fences to respond to increasing temperatures and rainfall affecting the performance of the industry. The measures taken have also helped to address impacts of warmer weather on field workers.

Box 4. Example of the use of living fences and reforestation to deal with a changing climate in Costa Rica

Company or association: Anonymous
Region: Costa Rica

Increase in temperatures and change in rainfall patterns, including increases in rainfall, have negatively impacted the pineapple production sector. For example, higher temperatures have caused burns and other internal problems in the fruit; while rains cause post-harvest problems since the higher water content in fruit affects its consistency, making it more difficult to transport, reducing its shelf life and generating problems of mould rot. In addition, climate change has increased production costs with respect to soil preparation, and crop and worker protection, especially in terms of solar radiation.

To respond to some of these challenges, the company aims to mitigate climate effects through different actions. The company has begun reforestation programmes and the implementation of living fences to preserve the health of the soil and local ecosystems and to promote conservation areas. It reports at least 10 percent of productive land has been incorporated into this programme, especially on farms that are less suitable for production. These projects also aim to connect biological corridors to enhance biodiversity; and are accompanied by a mapping of plant species, especially fruit trees, that could be associated with pineapple, and that may prevent the presence of new pests and predators.

The implementation of living fences has included the planting of commercially valuable timbers such as teak, which will not only address risks associated with heavy rainfall and higher temperatures, but also generate additional income for pineapple producers.

Since rising temperatures and radiation also impact field workers, the company has installed hydration stations on plantations and offered sun protection to workers, to prevent dehydration and other risks associated with heat stress and skin disorders. Following these measures, workers have reported less health concerns and are requesting fewer days sick leave associated with heat exposure.

It is important to note that some regulations in international markets have prevented the planting of other herbaceous species in pineapple plantations due to phytosanitary regulations. This could potentially discourage producing farms to take more sustainable approaches to improve their adaptation capacity.

Chapter 5.

Discussion and conclusions

Adaptation to climate change is required to ensure the continuity of global pineapple production and trade. Adapting to climate change will enable companies and producer associations to protect their production systems and care for their environment and workers, while minimizing the creation of new risks associated with increasing GHG emissions and global warming. Climate adaptation will thus contribute to the resilience and sustainability of agricultural value chains.

Although climate change and its associated impacts will be felt differently both across and within producing countries and regions, **extreme weather events will increase in frequency and intensity**. Moreover, it is expected that **multiple climate risk factors will occur concurrently** in the same regions, which in combination with other non-climatic factors such as economic slowdown or pandemics, will increase the overall risk to agricultural production systems. As such, pineapple producers need to be prepared to deal with multiple risks in a synchronized manner, so that they can maximize the benefits from synergies associated with combining adaptation practices. This approach will also help to minimize the risk of natural systems reaching adaptation limits – a key risk factor identified in the IPCC report in the face of ongoing increases in global warming (IPCC, 2023).

Knowledge and information on how to adapt to climate change in the pineapple sectors already exist, and many companies and producer associations are taking a proactive role in designing strategies and testing practices in the field to deal with climate change and extreme weather events. Chapter 4 of this guide highlights some of the existing technologies, practices, techniques and systems that can help producers to deal with ongoing changes and to prepare for and prevent future adverse climate impacts. Examples of good adaptation practices from companies and associations are also featured.

Many of the adaptation practices identified cut across different commodity sectors and are likely to be relevant for all tropical fruit production systems (e.g. drainage systems, early warning systems, integrated pest management, integrated water management, mulching and cover crops, waste management, wind breaks and living fences), while other practices identified are specific to the adaptation needs of pineapple (e.g. artificial flower induction, crop rotation, intercropping and solar protectors). The selected **adaptation practices address multiple climate risks and associated impacts simultaneously**. This is important to highlight, as discrete adaptation strategies that deal with only one risk factor at a time are less likely to achieve the desired impact in the way that combining many practices will.

Climate adaptation is a continuous process that takes time and requires investments in information and data. Regular data and information updates on production factors and climate trends are needed in order for adaptation practices to stay relevant. Companies and producer associations may consider developing adaptation strategies that take into account short-, mid- and long term projected climate trends. They also need to bear in mind that some practices might become obsolete as global and local temperatures and precipitation patterns change. This may require them to continually invest, explore and adopt new approaches to transform their production systems to ensure fruit supply in the longer term. A detailed assessment of the expected climate risks and impacts in each producing region and localities might be necessary to make the adaptation strategy as responsive as possible. The collection of climate data both on farm and by public institutions in localized areas is needed to support this process. Capacity building support for producers on how to interpret this data and incorporate this information into their decision-making processes is also required.

Adaptation and mitigation efforts to reduce greenhouse gas emissions should go hand-in-hand whenever possible. Adopting adaptation practices that have climate mitigation potential will help to not only reduce GHG emissions but may also potentially extend the shelf-life of available adaptation practices. Likewise, mitigation strategies can also be designed in a way to contribute to and reinforce adaptation. Some of the adaptation practices identified for pineapple production such as sustainable soil management, agroforestry, waste reduction and management, also have positive effects on reducing greenhouse gas emissions in the production sector. These practices also have important implications in storing carbon, for instance through improved soil health or increased biomass, making pineapple production more sustainable.

The adoption of adaptation technologies and practices requires some key considerations:

- **Damage allowance:** Some level of fruit loss/damage may be unavoidable in adaptation, especially during the early stages of introducing the practice. For example, when implementing integrated pest and weed management practices, producers may need to tolerate the presence of a minimum number of pests, diseases and weeds to allow for a natural re-balancing of the ecosystems. Also, phasing out synthetic fertilizers may mean a reduction in yield in initial phases as the soil properties and structures are restored. The level of damage farmers and companies are willing to assume will depend on their own income and adaptation needs, and the long or short-term vision guiding the management of the operation.

- **Investment costs:** Producers, associations and companies need to assess the investments required to integrate new technologies or techniques into the production system as well as the benefits, including environmental and social benefits. These may include costs associated with losses and damage of production and infrastructure, and health risks among others, if no action is taken. A cost–benefit analysis might be needed to assess the advantages and costs the companies would incur in a business-as-usual scenario versus a scenario where the adaptation strategies are implemented.
- **Time requirements:** The development of some adaptation practices may take longer than others, thus requiring a longer time horizon and greater investment to move from concept to implementation. Some of these adaptation solutions include the development of climate-resilient seeds, plants and genetic material, as well as the configuration of early warning systems.

All adaptation practices should aim to take into account all three dimensions of sustainability. While the environmental dimension is the clear entry point to promote adaptation in the tropical fruit sector, addressing social risks (e.g. health of workers) and economic risks (e.g. increased costs of inputs) associated with climate change impacts is also crucial to the long term sustainability of business operations.

To date, there is **limited evidence on the social impact of climate change** on the livelihoods, health and safety of producers and workers operating in pineapple value chains. However, some research points at the high vulnerability that workers face in agrifood value chains, particularly field workers, due to extreme weather events. This is linked to the strenuous nature of the work that is performed primarily outdoors, usually under inadequate working conditions (El Khayat *et al*. 2022). Some pineapple producing companies in Costa Rica have already noted these risks, especially those related to **heat stress and associated illnesses** derived from increasing temperatures and solar radiation.

The country risk profiles developed by the World Bank indicate that an increase in the frequency of heat waves and resultant heat stress on workers will become more prevalent in coming years, particularly in producing countries such as Costa Rica, Ecuador, Ghana, and the Philippines, with associated loss of labour productivity and risk to human life (World Bank, 2021). Heat stress is known to increase mortality and morbidity for the most vulnerable, especially the elderly, children and pregnant women. Additionally, children's learning ability significantly decreases with increased heat exposure. Other projected health stressors associated with climate change and identified across many of the countries included in the guide, include an increase in air pollution, asthma, vector-borne diseases (i.e. malaria, dengue, schistosomiasis, and tick-borne diseases), water-borne and food-borne diseases, and diarrheal diseases. Further efforts are required across all countries and sectors to better understand the impact of climate variability on human health and integrate strategies to deal with climate sensitive health issues into existing health programs and policies. Awareness raising and cross-ministerial dialogue will also be required to ensure that these issues are adequately reflected in other sectoral policies dealing with climate change, including the NAP-Ag plans, as the impact of climate change on human health will affect productivity in the agriculture sector and others.

The extent of impacts of climate change and the coping strategies available to the various segments of the population depends heavily on their socioeconomic status, sociocultural norms, access to resources, poverty as well as **gender** (FAO, 2018b; 2019b). **Women and youth are among the highest risk groups when it comes to climate change impacts**, yet no research could be found on specific impacts of climate change on women and youth vis-à-vis engagement in global pineapple value chains. This despite the important role women play in the harvesting and packing of this commodity. Gender-disaggregated research is urgently required to better understand the key factors that account for the differences between women's and men's vulnerability to climate change risks, and how to build tailored adaptation strategies to address these.

Other studies have shown that violence, including physical, psychological, and reproductive violence against women, is more pronounced after natural disasters, with other consequences on women's wellbeing (Sloand *et al*., 2015). Women and girls face increased risks of gender-based violence following a climate or other unexpected shocks (e.g. COVID-19 outbreak) (Sloand *et al*., 2015). For example, shocks tend to intensify domestic and social tensions due to increased unemployment, higher economic dependence of women on the breadwinning partner and shortages of basic services (e.g. food, water, roads). Gender-based violence has been an issue widely noted in other export-oriented agrifood value chains, including banana, grapes and vegetables (EBRD and CDC, 2019), suggesting that it could also be a concern in the pineapple sector.

As discussed throughout the guide, climate change will influence food production via direct and indirect effects on crop growth processes, which has **implications for food security and nutrition**. The breakdown in food systems due to higher temperatures, land and water scarcity, flooding, drought and displacement, will negatively impact agricultural production and disproportionally affect the most vulnerable people, who are already face hunger and food insecurity. Vulnerable groups risk further deterioration of available food and nutrition when exposed to extreme climate events. Pineapples form part of a healthy diet and are an important source of vitamins and nutrients for consumers in both the producing and importing countries. On this basis, pineapple companies could consider how they may be able to support vulnerable populations in their local communities through targeted social outreach programmes that aim to improve food security and nutrition such as public procurement (e.g. school feeding programmes, community canteen services) or food banks.

The Responsible Fruits Project recognizes that **enhancing the adaptive capacity and climate resilience of the pineapple value chain cannot be achieved through a single-actor approach**. The complex challenges associated with climate change impacts are best solved through the cooperation of stakeholder groups including governments, companies, producer organizations, research and training institutes, worker unions, and other civil society organizations. Establishing mechanisms for multistakeholder collaboration may be the most effective approach to tackle the impacts of global warming on the pineapple industry in the future. Current adaptation solutions highlighted in this guide and existing gaps in knowledge (e.g. integrated pest management and early warning systems) demonstrate that efforts are needed across the industry in all producing countries to engage with other stakeholders. These include research institutions and relevant ministries to increase the availability of sustainable climate adaptation solutions identified through research and development, and to promote widespread adoption through government incentives and policy dialogue. The adoption of adaptation practices not only requires the development of new technologies, but also technical assistance (e.g. through extension services and targeted capacity development programmes), information exchange (e.g. climate data and alerts, information on emerging pathogens, etc.) and available financing/incentives for the uptake of new, and potentially risky, technologies and practices.

At an institutional and policy level, FAO's work to support countries to integrate adaptation solutions specifically for the agriculture sector as part of the broader National Adaptation Plans developed by countries in line with their NDC commitments is an essential step. While the NAP-Ag plans developed for the two countries included in this guide (i.e. the Philippines and Thailand) do not focus specifically on the tropical fruit sector, many of the adaptation measures proposed are relevant for tropical fruit production and have been discussed in **Chapter 4** of the guide (e.g. water management, soil conservation, protection of biodiversity, agroforestry, early warning systems). **Understanding how specific commodity sectors like pineapple production and export can contribute towards the achievement of mitigation and adaptation targets set out in the NDCs and NAPs is useful.** Improved understanding may help the industry to align their efforts with those at a national and sub-regional level and demonstrate to policy makers that collective efforts are being made by industry in support of these plans. Efforts to generate evidence of the impacts of implementing adaptation practices through better monitoring and evaluation is also needed to further advance these claims.

The Responsible Fruits Project is committed to supporting pineapple producers and exporters globally to deal with climate change and other identified sustainability risks through the generation of practical tools. The project has been working on different technical materials and tools tailored to the pineapple industry, and some applicable to the wider tropical fruit sector. These products are discussed below.

The gap analysis guide helps companies to compare the standards and policies they use with the OECD-FAO Guidance for Responsible Agricultural Supply Chains, the global benchmark for due diligence and responsible business conduct in the agriculture sector. By using the gap analysis tool, companies can assess and identify how their operations are impacting the ecosystems in which they operate and identify any negative influence they may be having on the environment and climate (among other factors). By identifying these risks and learning how to manage them, companies can improve their business performance, increase sustainability, and strengthen resilience to external shocks, including climate risks. In many countries, newly passed or proposed laws require companies to carry out risk-based due diligence to identify, assess, mitigate, prevent, and account for how they address actual and potential adverse impacts of their activities and those of their suppliers and business partners. These include areas related to use of agrochemicals and natural resources management, both with direct impacts on climate adaptation and mitigation.

The project's ongoing work to develop a carbon and water footprint measurement tool for the pineapple industry also contributes to this goal. The carbon and water footprint measurement tool aims to support producers, companies and associations to better understand how they can reduce their carbon emissions and prevent the degradation of water resources through their operations. By increasing this understanding, the tool also aims to encourage the adoption of climate-smart practices and efficient water management in the pineapple value chain as part of the companies' environmental strategy. The project also expects that the tool will fill a gap in development costs for the industry, especially for small-sized companies and producers, as well as in knowledge gaps for farmers who may lack user-friendly tools to measure carbon and water footprint efficiently. The tool will be available for use in late 2023.

The project has also carried out a series of technical webinars addressing some of the most pressing climate challenges to the pineapple sector. These include deforestation prevention, use of agrochemicals and maximum residues limits, water monitoring and use, climate change adaptation, biodiversity protection, reduction of loss and waste and soil health and land degradation.

In addition, the project conducted a detailed study to understand the resilience challenges the pineapple sector is facing. Climate change and variability feature prominently as a key resilience challenge facing the industry. Based on the results from this study, the project will elaborate a technical guide, technical briefs and capacity development activities to address areas that directly and indirectly support companies' efforts to adapt and transform vis-à-vis future extreme weather events and a changing climate. The technical guide will focus on supporting businesses and associations in the pineapple industry to better track and report on their progress towards resilience and sustainability. In conclusion, this guide was produced by the Responsible Fruits Project for producers and exporters of pineapple who are interested in learning more about climate change in the context of their own business systems and how they can adapt to the effects of climate change. It is hoped that for many the guide will be the starting point for discussion on national, regional and localized climate change impacts on pineapple production and stimulate joint planning for research on adaptation solutions to support the long term sustainability of the export industry. The limitations of the guide were acknowledged in **Chapter 1**, given the lack of time and resources to conduct the field-based, longitudinal scientific research that is needed to answer specific questions related to climate change impacts over time for pineapple under various production conditions. Indeed, more longitudinal research that is commodity and location-specific is needed to better understand climate risks and long term effects on tropical fruit crops and identify innovative adaptation solutions.

Annex 1

Suggested resources

The lists below provide additional reference material, such as websites, technical publications and guidance materials, policy briefs, etc. that can support producers, associations and companies to learn more about climate change, its impacts on the tropical fruit sector and adaptation options available. Some toolboxes are also suggested that may help stakeholders in the pineapple industry to define their adaptation goals and track progress towards these.

Technical and guidance publications and articles

Pineapple

Alla, M.J.M. 2021. Agricultural productivity of selected Philippine Crops: Effect of climate change in Cotabato Province. *International Journal Innovative Science and Research Technology*, 6(12). 1127–1131 p. www.ijisrt.com/assets/upload/files/IJISRT21DEC732.pdf

CANAPEP. 2022. Manual técnico para la producción sostenible de piña. Available at: https://canapep.com/wp-content/uploads/2022/05/MANUAL-TECNICO-PARA-LA-PRODUCCION-SOSTENIBLE-DE-LA-PIN%CC%83A-V08.pdf (Spanish only)

Díaz Ramírez, L., Jäger, M. & Hurtado, J. 2021. *Plan de investigación y desarrollo de la cadena productiva de la piña del Valle del Cauca a partir de sus principales brechas tecnológicas*. Universidad Nacional de Colombia. https://repositorio.unal.edu.co/handle/unal/80897 (Spanish only)

Díaz Ramírez, L., Hurtado, J. & Jäger, M. (2022). *Brechas tecnológicas de la cadena productiva de la piña en el Valle del Cauca y descripción del estado del arte*. Universidad Nacional de Colombia. https://repositorio.unal.edu.co/handle/unal/82689

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Pulhin, F.B., Lasco, R.D., Espaldon, M.V.O. & Gevana, D. 2009. Mainstreaming climate change adaptation in watershed management and upland farming in the Philippines. *Forestry Development Center, College of Forestry and Natural Resources, University of the Philippines Los Banos, Los Banos*,.1–65 p. www.weadapt.org/sites/weadapt.org/files/legacy-new/placemarks/files/5077e5858239dphilippines-final-report-draft.pdf

Rafanan, K. F. A. 2016. Effects of climate variability on the business performance of pineapple growers in Calauan, Laguna, Philippines. *Undergraduate Theses*. 4577. University of the Philippines Los Baños (UPLB). www.ukdr.uplb.edu.ph/etd-undergrad/4577

Reinhardt, D.H., Uriza, D., Soler, A., Sanewski, G. & Rabie, E.C. 2019. Limitations for pineapple production and commercialization and international research towards solutions. *Acta Horticulturae*. 1239. 51–64 p. https://doi.org/10.17660/ActaHortic.2019.1239.7

Whitney, C., Fernandez, E., Do,H., Luu, T.T.G., Heuschkel, Z. & Luedeling, E. 2020. *Decision Support for determining effective climate measures in banana production*. University of Bonn. www.nachhaltige-agrarlieferketten.org/fileadmin/user_upload/Banana_adaptation_measures_report_UniBonn.pdf

Production sector in general

FAO. 2023. SEPAL (*System for earth observation data access, processing and analysis for land monitoring*). Rome. www.fao.org/3/cb2876en/cb2876en.pdf

Global Nature Fund. 2023. Biodiversity check agrícola. German Agency for International Cooperation (GIZ). Germany. www.delcampoalplato.com/en/home-engl/biodiversity-check-agricola-engl

Miles, L., Agra, R., Sengupta, S., Vidal, A. & Dickson, B. 2021. Nature-based solutions for climate change mitigation. IUCN and UN Environment Programme. www.unep.org/resources/report/nature-based-solutions-climate-change-mitigation

Pronaturaleza – Fundación Peruana por la Conservación de la Naturaleza. 2021. *Biodiversity hotspot of the tropical Andes*. Perú, Critical Ecosystem Partnership Fund. www.cepf.net/sites/default/files/tropical-andes-ecosystem-profile-2021-spanish.pdf

United Nations Environment Programme. 2015. Microfinance for ecosystem-based adaptation measures – Options, costs and benefits. Panama. www.unep.org/resources/publication/microfinance-ecosystem-based-adaptation-options-costs-and-benefits

Toolboxes and websites

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