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CLIMATE ADAPTATIONS FOR SMALLHOLDER COFFEE PRODUCTION SYSTEMS IN PAPUA NEW GUINEA

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Table of Contents

List of Figures

List of Tables

List of Plates

Executive Summary

Smallholder coffee production in Papua New Guinea (PNG) is vulnerable to the effects of climate change and is already reshaping the environmental conditions in which coffee is grown, particularly in the highland growing regions, with rising temperatures, variable rainfall, and increased pest and disease pressures threatening both yield and quality. PNG's coffee system vulnerability is compounded by limited access to extension services, market volatility, low-input farming practices, and household labour constraints. Despite these challenges, PNG's smallholder farmer's resilience and adaptability create opportunities for targeted climate adaptation strategies.

Existing research and preliminary modelling show the mean annual temperatures are expected to increase by 1–2 °C by 2050 in PNG's main arabica coffee growing region. While higher altitudes may become more suitable for coffee production, lower-altitude regions are likely to be less suitable. Rainfall projections remain uncertain, but increased variability and intensity are expected, further complicating crop management and increasing the risk of drought and soil erosion. Attention to climate adaptation practices in these regions will be particularly important.

The high altitude of PNG's arabica coffee growing regions means the climatic effects are likely to be less severe than those in many other global coffee growing regions. However, the prevalence of low-input farming systems in PNG, and declining government extension services, are likely to restrict farmers' ability to adopt new technologies and coffee garden management practices, thereby limiting adaptation.

This report explores a range of climate adaptation strategies to create more resilient smallholder coffee systems in PNG, including:

- *Improving coffee garden management* – improving shade levels, coffee tree pruning practices and rehabilitation, and soil moisture and nutrient management strategies.
- *Diversifying incomes* – expanding secondary income shade tree plantings, intercropping, and supporting farmers' livelihoods beyond the coffee garden.

- *Planting climate resilient coffee varieties* – using existing varieties and introducing new varieties.
- *Changing the location of coffee gardens* – planting coffee at higher elevations and in more suitable local microclimates.
- *Transitioning away from coffee* – for the most vulnerable areas when other adaptation measures are unviable.

This report includes an evaluation of the suitability of, and risks associated with, the different adaptation strategies within the socio-cultural context of PNG's smallholder coffee farming and livelihood systems. It also identifies factors that may influence the likelihood of their adoption. These include:

- *Diverse livelihoods*
- *Livelihood priorities*
- *Returns to labour*
- *Low-input production strategies*
- *Gendered division of household labour and household decision making*
- *Household labour availability*
- *Land ownership and access*

Based on this evaluation, the following are recommendations for the PNG coffee industry:

1. *Adopt a whole system approach to climate adaptation*.

Successful climate adaptation in coffee systems requires a whole-of-system approach that recognises farmers' broader agricultural systems and diverse livelihoods.

2. *Diverse adaptation approaches are needed*.

Coffee in PNG is farmed in diverse environments and altitudes, and different approaches are relevant to each. Smallholder coffee farming families are also diverse, and this must be considered before implementing any adaptation strategies.

3. *Prioritise low-input approaches*

Climate adaptation approaches that align with the low-input production strategies used by most smallholder coffee farmers are more likely to be successful. Household labour constraints will be a major limiting factor to adoption. Technologies and approaches that reduce labour inputs are more likely to be adopted.

4. *Support more equitable coffee farming systems*

Engaging women and youth in coffee farming, and improving the benefits they derive from coffee systems, will be critical to the adoption of many climate adaptation practices. Approaches that improve returns to labour will help support adoption.

5. *Strengthen extension services and farmer training*

Reinvesting in coffee extension services to improve historically low adoption rates among farmers is vital. Engaging the private and NGO sectors, exploring strategies to support farmer-to-farmer knowledge sharing, and investigating new communication and learning approaches will also be beneficial.

6. *Improve current coffee systems*

Strategies such as improving shade to buffer temperature extremes, improving soil health, and reducing pest pressure will create coffee systems that can adapt to the short-term shocks of climate change, and build resilience to long-term effects. These changes should also build on local innovations and current coffee systems.

7. *Support smallholder management of coffee berry borer (CBB)*

CBB is a serious existing threat to smallholder coffee in PNG, and infestation is likely to spread and intensify in a warmer climate with more intermittent rainfall.

1. Introduction

Coffee ranks among the most traded commodities globally (Amrouk et al., 2025). Throughout the value chain it supports the livelihoods of more than 125 million people, driven by high demand and great export potential (Freitas et al., 2024). Rising temperatures, shifting rainfall patterns, and increasing pest and disease incidence are now threatening both the quantity and quality of coffee yields worldwide (Ogundeji et al., 2019). Globally, climate change is predicted to substantially reduce the land area suitable for coffee production (Bunn et al., 2014; Grüter et al., 2022). Developing effective climate adaptation strategies will be critical to meeting increasing global demand and to supporting the livelihoods of coffee farmers. Globally, around 60% of coffee is produced by smallholder farmers, many of whom experience poverty (Rushton, 2019). These farmers will require external support to help them to adapt.

Papua New Guinea (PNG), in the Southwest Pacific, is a relatively small producer of coffee, accounting for less than 1% of global production in 2023 (ICO, 2024). Domestically, however, coffee is PNG’s second-largest agricultural export commodity. Between 2020 and 2024, coffee exports, most of which were arabica coffee, averaged PGK 590 million per year (Bank of PNG, 2025). Coffee is particularly important for the rural people in the highlands region, where it is the primary source of income for 80% of households (Curry et al., 2017).

Historically, PNG has had an excellent reputation for high-quality coffee, and smallholder farmers, who produce most of the country’s coffee, have been able to earn cash from the sale of ripe coffee cherries, parchment and green beans. However, the yield and quality have declined since the late 1990s, as the industry struggles with quality control, pests, and diseases, poor returns for labour for smallholders, and declines in extension services (Curry et al., 2017). A key challenge is to improve the coffee production systems in PNG to increase the yield and quality, and to make them more sustainable and resilient to current and future biotic and abiotic threats. There is a high potential for PNG's coffee industry to grow and contribute high-quality coffee for export, supporting the country's economic growth.

This report includes some findings from the ACIAR-funded study *Evaluating carbon markets as a pathway to establishing climate-resilient coffee agroforestry systems in Papua New Guinea (CLIM/2024/101).* This work builds on climate change-relevant research activities already being conducted by CIC. Data were collected through workshops and consultations with researchers and extension officers in 2024 and 2025, and through field visits to smallholder farming communities and their coffee gardens, as well as to CIC agricultural trial sites. The report also draws on previous ACIAR-funded research with smallholder coffee farmers in PNG.[1]

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[1] Improving livelihoods of smallholder coffee communities in Papua New Guinea (ACIAR ASEM/2016/100); Improving livelihoods of smallholder families through increased productivity of coffee-based farming systems in the highlands of Papua New Guinea (ACIAR ASEM/2008/036); and Identifying opportunities and constraints for rural women's engagements in small-scale agricultural enterprises in Papua New Guinea (ACIAR ASEM/2014/054).

2. Coffee and climate change

World coffee production is based on two species: robusta (*Coffea canephora*) and arabica (*Coffea arabica*), with the latter being of higher quality and accounting for approximately 60% of global coffee production (Pham et al. 2019). Arabica coffee does not grow well in high temperatures; therefore, the predicted climate changes are expected to have a considerable influence on its production (Bunn et al., 2015). This report focuses on the production of arabica coffee, which accounts for over 95% of PNG coffee exports (CIC, 2020).

Research into the effects of climate change on coffee production and adaptation options to mitigate these effects has been conducted in the world's largest coffee-growing regions (Pham et al., 2019), but PNG's coffee-growing regions are seldom included. Thus, there is a need for further research in this area to mitigate the vulnerability of PNG's coffee industry.

Coffee trees are typically productive for 20 to 50 years, with climatic conditions determining the suitability of the location and the type of coffee that can be produced. Coffee is generally grown between latitudes of 22 °N and 26 °S, as altitude contributes significantly to temperature variation (Descroix and Snoeck, 2012). Arabica has an optimal temperature range of 18 °C to 22 °C. At temperatures above 23 °C, coffee cherry development and ripening accelerate, leading to reduced quality, while temperatures below 17 °C depress growth (CSIRO and SPREP, 2022). Optimal rainfall is between 1,500 mm and 1,800 mm, with a short marked dry period followed by rain beneficial for initiating flowering (Pham et al., 2019; CSIRO and SPREP, 2022). The optimal relative humidity for arabica is between 60% and 75% (Wintgens, 2012).

The appropriate climatic conditions during the vegetative and reproductive phases of coffee trees are crucial (Pham et al*.,* 2019). Changes in temperature and delays or shortages in precipitation can hinder fruiting and affect bean quality (Gokavi and Kishor, 2020). The Intergovernmental Panel on Climate Change (IPCC) estimates a global warming of 1.2 °C to 3.0 °C by 2050 (Grüter et al., 2022). Extensive climate modelling has shown these temperature increases will reduce production in most of the world's coffee-growing regions (Bilen et al., 2022). In a recent systematic review on the effect of climate change on global coffee production, Pham et al. (2019) found that most report a decline in coffee yields, loss of optimal growing areas, and increased incidence of pests and diseases, including priority pest species. Climate modelling suggests production in the highly suitable coffee arabica-growing areas of Brazil, Vietnam, Indonesia, and Colombia is projected to decrease by 53.7% combined under future emissions scenarios (Grüter et al., 2022). Production in the moderately suitable regions is expected to decline by 31% (RCP 2.6, low emissions scenario) to 41% (RCP 8.5, high emissions scenario).

Research also shows that growers can expect changes in the timing and intensity of flowering, fruit development, and ripening (Parada-Molina et al., 2025). These changes will be caused by rising temperatures, more variable rainfall, and increased water stress. A recent study in Veracruz, Mexico, found that water demand peaks during flowering and ripening phases, and climate variability to significantly affect uniform flowering and bean ripening (Parada-Molina et al., 2025). In PNG, CIC researchers and coffee farmers have observed an increased period of dry weather and intermittent rainfall, leading to more flowering periods and a longer picking period within a season.

Drought will also affect coffee production, although more research is needed to understand the effects (Pham et al. 2019). The timing of drought in relation to the plant's reproductive phases is important, as demonstrated by the effect of the 1997 drought in PNG on coffee yields. In 1997, although the timing of the usual seasonal dry period shifted considerably, coffee production was not affected as there was adequate soil moisture during the coffee cherry development phase (Hombunaka and von Enden, 2001). It is difficult to accurately predict rainfall data; however, many researchers agree that drought conditions are expected to increase in frequency and severity in many of the world's coffee-growing regions (Pham et al., 2019). Climate change and variability, particularly increased drought conditions, are likely to affect the entire coffee supply chain, encompassing harvesting and processing activities (Pham et al., 2019).

Climate change is expected to have a significant influence on coffee physiology. Temperatures exceeding 23 °C can accelerate the development and ripening of coffee cherries, particularly in arabica varieties, often reducing the time available for complex sugars and flavour compounds to accumulate. Elevated atmospheric CO_2

concentrations, resulting from greenhouse gas emissions, may increase vegetative growth rates, potentially shifting the plant's energy allocation away from reproductive development and thereby reducing yield (DaMatta et al., 2018). When combined with rising temperatures, this accelerated growth can lead to premature flowering and fruit development, further shortening the maturation period and compromising bean quality. Additionally, high temperatures during pollination can induce floral stress and abortion, preventing fruit set. However, bean quality may not be affected under warming conditions and elevated CO_2 levels provided they have sufficient water (Rahn et al., 2018; Verhage et al., 2017). Further research is required to better understand the effect of the elevated CO_2 and its interaction with heat at higher altitudes on coffee bean chemical composition and quality (Ramalho et al., 2018).

Under climate change, pest and disease pressures, as well as their distribution, are expected to deviate from historical patterns. Rising temperatures and changes in rainfall patterns could lead to an increase in the numbers of priority pest species (Pham et al., 2019). For instance, the range of the coffee berry borer (CBB, *Hypothenemus hampei*), which can have devastating effects on the marketable quality of the bean, has expanded into high-altitude regions of East Africa (Davis et al., 2012). An increase in temperature by 1 °C leads to faster development of these beetles (Jaramillo et al., 2011). Furthermore, the spread of fruiting over a greater portion of the year means there will be no break in the CBB cycle, resulting in consistently high numbers being in coffee gardens (Curry et al., 2023).

Similarly, coffee leaf rust (CLR, *Hemileia vastatrix*), a disease that can reduce photosynthesis capacity, is more prevalent in high-altitude coffee production areas than it was several decades ago (Davis et al., 2019). Over the past 200 years, CLR has caused major losses in production and plant mortality, with greater effect in warmer locations (CSIRO and SPREP, 2022). Even a small increase in temperature and rainfall can increase the disease incidence pressure in PNG coffee regions, and with the difficulty of controlling this disease, the effect on production could be large (Allen and Bourke, 2009). Overall, climatic changes can significantly affect tree health, bean quality and production levels, and therefore, the livelihood of communities relying on coffee production.

3. Smallholder coffee production in PNG

Smallholder farming families produce around 85% of PNG's coffee (Allen et al., 2009; CIC, 2020), most of which is arabica coffee. Most smallholder arabica production occurs between 700 m and 2400 m, particularly concentrated between 1400 m and 1800 m (Allen et al., 2009; Bourke, 2018). Robusta coffee, produced in the lowlands, makes only a very small contribution to national production.

Coffee is generally grown in shaded systems. The amount of shading differs between gardens and within an individual garden. When coffee gardens are first established, they are typically intercropped with food crops, with bananas often used as temporary shade. Permanent shade trees such as casuarina are planted, and as these mature, the food crops are removed, leaving a predominantly coffee–casuarina system, although residual food crops are frequently present. Shade trees and fruit trees are often randomly planted throughout coffee gardens. There is considerable variation in the timing and sequence of the planting of the food crops, bananas, coffee and casuarina (Bourke 1985; Tilden et al., 2024).

Labour is generally provided by the immediate family, with some assistance from extended kin, mostly during the main harvest period (Plate 1; Curry et al., 2017). Garden maintenance is minimal (Curry et al., 2017). Trees are often old, and farmers accept high losses to pests and diseases. Smallholder yields are, as a result, generally low and well below commercial plantation yields (Allen et al., 2009; Sengere, 2016). Harvested yields are also low because of under-harvesting, mainly due to labour shortages and, frequently, prices that provide insufficient incentive for farmers, many of whom have alternative income sources and livelihood priorities (Curry et al., 2017; Koczberski et al., 2023b).

Plate 1. Family working in a coffee garden (Source: Tim Sharp, Curtin University)

The low prices paid to growers reflect global markets, but are also low due to poor postharvest processing by smallholders, reducing coffee quality. The falling value of the local currency has also contributed to steadily declining incomes from coffee. In response, many smallholders have reduced the labour (including harvesting) they invest in coffee, and some farmers have uprooted their coffee trees to expand production of fresh food for the domestic market. There is growing involvement in speciality and certified coffee markets, and these have supported improved prices for smallholders, however, this remains a relatively small proportion of exported coffee. Although most of the past 20 years have been characterised by declines in real incomes and declining smallholder interest in coffee, at the time of writing, coffee prices and smallholder interest are both very high.

Smallholder production is also affected by poor road infrastructure, market access, volatile international coffee markets, and a decline in extension service delivery (Imbun, 2014; Sengere et al., 2019; Sengere, 2016). Together these constraints have led to stagnating smallholder production since the 1990s. Today, coffee farmers are adapting their coffee systems, alongside their broader farming systems and livelihoods, to a range of different pressures and opportunities including a changing economic and social landscape, population growth and climate change. While there have been significant advances in identifying the effects of climate change on coffee production globally, there are limited studies that integrate the causal effects of climate change on production, and the nuances of different coffee agroforestry systems in the global coffee growing regions, particularly those of smallholder nature (Rahn et al., 2025).

4. The current climate for PNG coffee production

The climate in PNG is influenced by several factors, including the trade winds and the movement of the South Pacific Convergence Zone (SPCZ), a zone of high pressure and rainfall that migrates across the Pacific south of the equator. Year-to-year variability in climate is strongly influenced by the El Niño-Southern Oscillation (ENSO) system in the southeast Pacific, which typically delays the start of the monsoon season and brings drought conditions to PNG, especially in the southern areas of the main island, and frost at higher altitudes.

PNG has an equatorial monsoonal climate. Between 1981 and 2010, annual mean temperatures in PNG ranged from 15 °C to 30 °C across the country (Figure 1), with maximum temperatures of 30 °C to 32 °C. The main coffee growing regions of PNG are centred around Mount Hagen in the Western Highlands and Goroka in the Eastern Highlands. Mount Hagen has a mild tropical climate with average temperatures ranging from 13 °C to 21 °C throughout the year, while Goroka has a similarly consistent climate, with average temperatures between 15 °C and 25 °C (World Weather Online, 2026). Coffee production in PNG is predominantly located in these areas due to these favourable temperatures, altitude and rich volcanic soil (Sengere, 2020).

Two monsoon seasons are recognised in PNG: the northwest monsoon, which occurs from December to March, and the southwest monsoon, which occurs from May to October. PNG has one of the wettest climates in the world, with rainfall in many areas exceeding 2,500 mm annually and averaging 200 to 400 mm per month, even during the dry season (Figure 1). The heaviest rainfall is usually around the highlands fringe. There are pronounced wet and dry seasons in some coffee-growing locations, including in the Eastern Highlands and the Bulolo Valley. Under current climate conditions, the optimal growing regions for coffee production in PNG include the highland regions around Goroka and Mount Hagen. The spatial variations in modelled historical temperature and rainfall in PNG are illustrated in Figure 1 (modelled temperature and rainfall were used due to a lack of observational data).

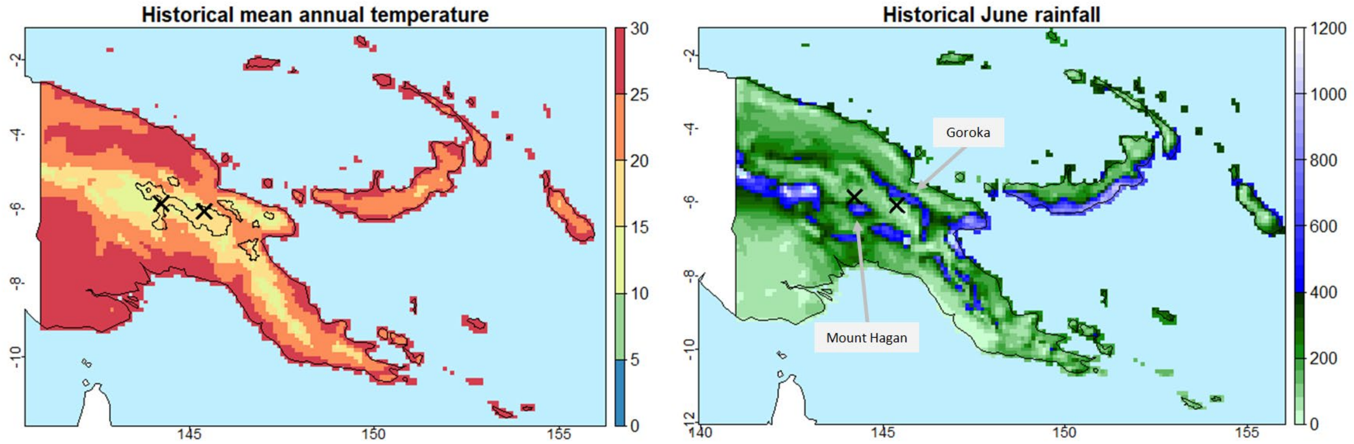

Figure 1: Modelled historical annual mean temperatures (left) and total rainfall for the dry season month of June (right) in Papua New Guinea[2]

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[2] The black outline shows key production regions for arabica (Allen et al., 2009).

5. Future climate implications for PNG coffee production

Regional climate models and projections were used to assess the potential effects of climate change on PNG coffee production and to identify possible adaptive strategies for growers. PNG has a complex topography and a diverse range of climate zones, with significant gaps in weather data throughout the region. Understanding climate change in PNG is challenging due to the lack of historical data to validate modelling data.

As part of the Australia-Pacific Climate Partnership (APCP) funded project, 'Next Generation Climate Projections', the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat of the Pacific Regional Environment Programme (SPREP) updated and improved climate change projections for 14 Pacific Island countries (Table 1). The aim was to provide improved climate information, including projections for temperature, rainfall, and sea-level rise, tailored to the specific needs of the region and its various sectors.

This project included a case study on climate hazard-based effects on coffee production in PNG, which suggests the following implications (CSIRO and SPREP, 2022).

- Average daily temperature optimum of 18–21 °C may be exceeded.
- With higher minimum temperatures, coffee leaf rust (CLR) may increase.
- Average rainfall, including in parts of the PNG highlands, may increase.
- Extreme weather conditions, such as higher rainfall intensity and drought pressure, may increase, causing challenges for preventing waterlogging and controlling soil moisture.

Based on these climate projections, CSIRO and SPREP (2022) highlighted the following high-level adaptation options:

- Adjusting management practices to minimise exposure to extreme temperatures and rainfall.
- Diversifying farming systems.
- Planting coffee at higher altitudes.

Table 1. Standardised scenarios for Papua New Guinea for the period 2040–2059 relative to 1986–2005 for low and high emission pathways and two climate change scenarios. (Sourced from CSIRO and SPREP, 2021)

	Scenario 1 **Monsoon does not intensify**	**Scenario 2** **Monsoon intensifies**
Low emissions (RCP2.6)	Warmer Annual temperature: +0.7 °C Annual rainfall: no change More heatwaves No change to humidity and solar radiation. Heavier rainfall Greater tropical cyclone intensity Sea level rise: 17–29 cm	Much warmer and wetter Annual temperature: +1.3 °C Annual rainfall: +5 to +10% (mainland), +25% (islands and ocean) More heatwaves More humidity Less solar radiation Much heavier rainfall Greater tropical cyclone effects Sea level rise: 17–29 cm
High emissions (RCP8.5)	Much warmer Annual temperature: +1.2 °C Annual rainfall: no change More heatwaves No change to humidity and solar radiation Heavier rainfall Greater tropical cyclone intensity Sea level rise: 21–36 cm	Hotter and much wetter Annual temperature: +2.1 °C Annual rainfall: +25% Many more heatwaves More humidity Less solar radiation Much heavier rainfall Greater tropical cyclone intensity Sea level rise: 21–36 cm

NSW DPIRD built upon existing climate projections and data analyses to identify further work that requires climate projections. This work aimed to validate climate data for PNG and, subsequently, to develop climate impact models of crop physiology for coffee, providing an overall climate vulnerability assessment of coffee grown in PNG.

Climate projections for PNG have been calculated based on the Queensland Government's new QldFCP-2 projections dataset. This dataset uses an ensemble of 15 regional climate models at a 20 km resolution. The mean temperature and rainfall were averaged over the models, for the intermediate emissions scenario, SSP2-4.5. The historical climate data presented have also been derived from the QldFCP-2 dataset, due to a lack of observations available from the PNG area. The suitable growing areas for coffee have been identified as those where average annual temperatures range between 17 °C and 21 °C.

Climate projections show temperatures in PNG are likely to be higher by the 2050s. Temperatures in higher-elevation areas associated with arabica coffee production are expected to be between 1.5 °C and 2 °C warmer. Goroka's mean annual temperature is projected to increase from 16.9 °C (historical) to 18.6 °C. The projections are not predictions but rather, they describe plausible climate conditions for different scenarios that specify anthropogenic greenhouse gas emissions over the coming decades. In this scenario, annual mean temperatures throughout PNG are likely to be 1 °C to 2 °C warmer in the middle of the 21st century (Figures 2 and 3).

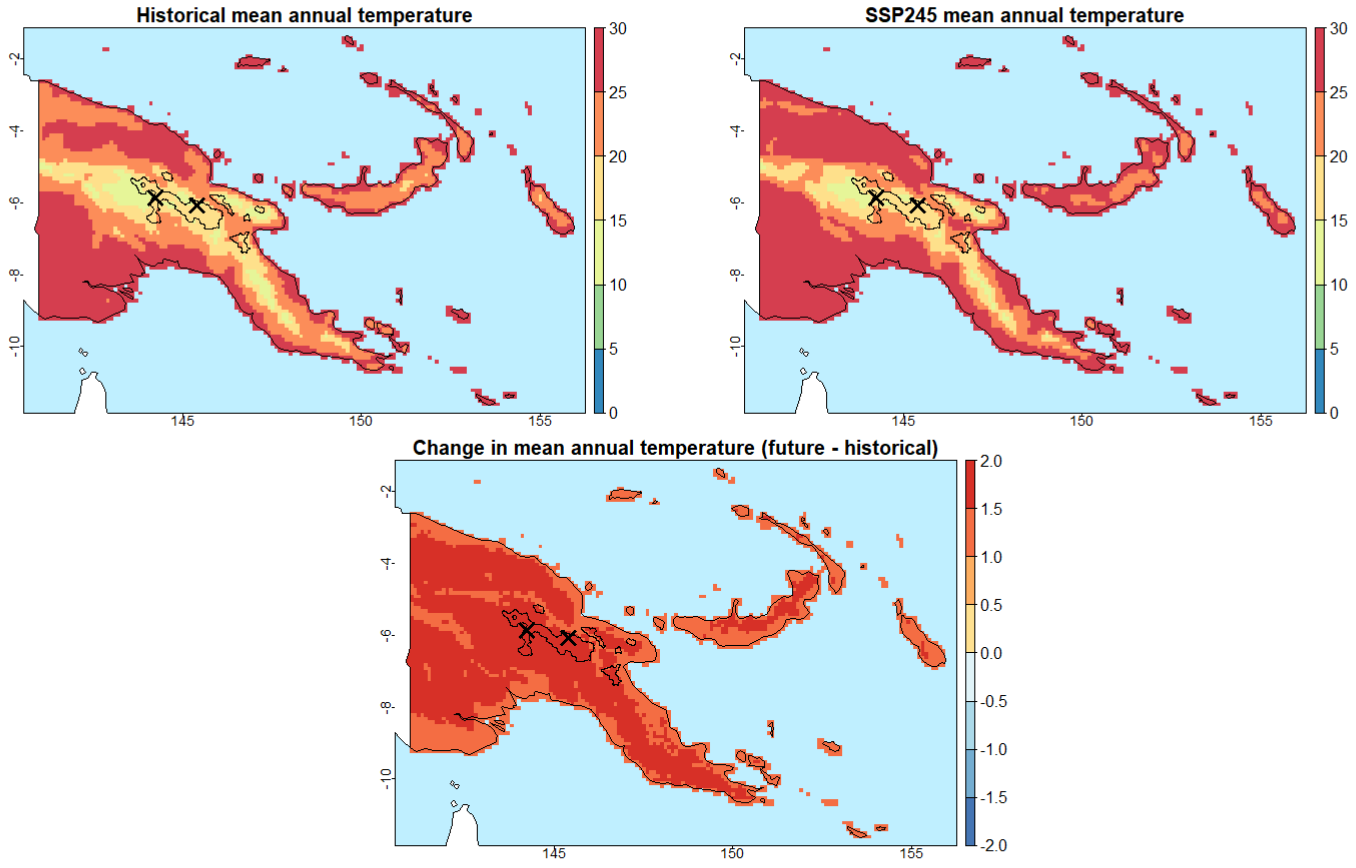

Figure 2: Historical and predicted mean annual temperature, and predicted change in mean annual temperature, for PNG (°C)[3]

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[3] The annual mean temperature is shown on a colour scale from blue and yellow (cooler) to red (warmest) for historical (top left) and future (top right) times. These maps highlight temperature variations in PNG, with the change map (bottom) capturing the modelled difference between the historical period (1980–2010) and the future (2040–2070). The black outline shows key production regions for arabica (Allen et al., 2009). Modelled temperature for the historical period was used due to a lack of observational data.

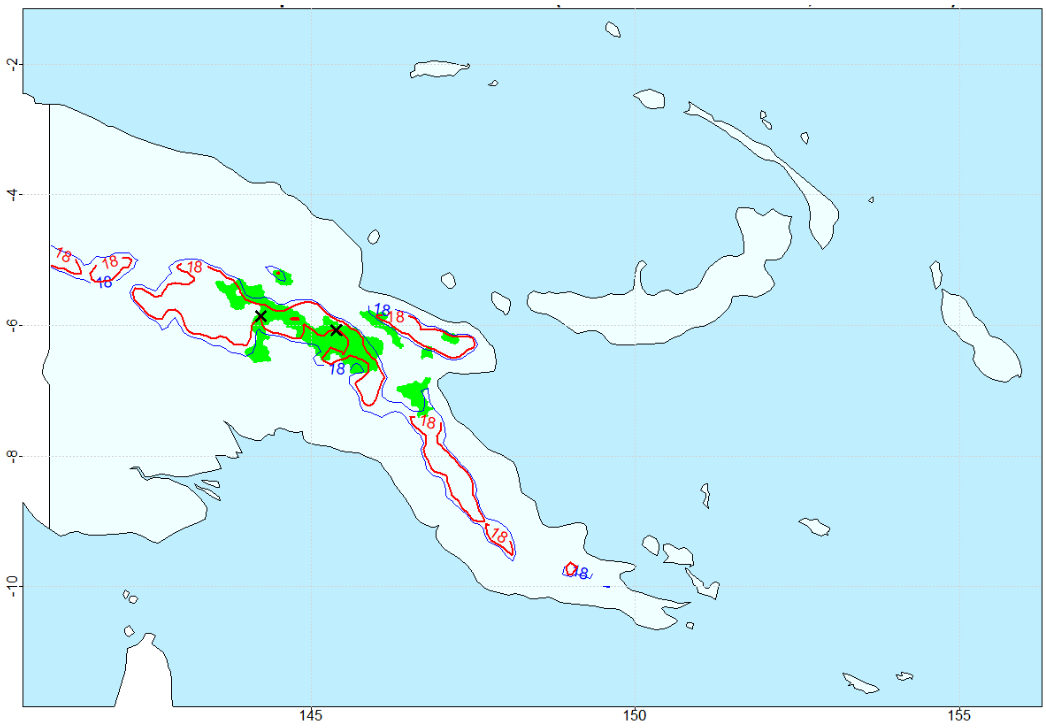

Figure 3: Mean annual temperature contours under the intermediate scenario SSP2-4.5 modelled for 18 °C in PNG[4]

Climate projections for rainfall are more uncertain, and no discernible trends can be identified (Figure 4). Of the ten underlying climate models used for these maps, all indicate only small changes in rainfall at Goroka (Figure 5). However, five of the climate models predict increases in rainfall between March and June. There is a strong need for improved rainfall data collection in PNG, particularly in the coffee production regions.

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[4] A mean annual value of 18 °C was selected as an indicative threshold for coffee production. The blue line represents the modelled historical contour for 18 °C, while the red line indicates the projected future 18 °C contour, under the intermediate scenario SSP2-4.5. Green areas indicate the region of significant arabica production (Allen et al., 2009). Modelled historical temperature was used due to a lack of observational data.

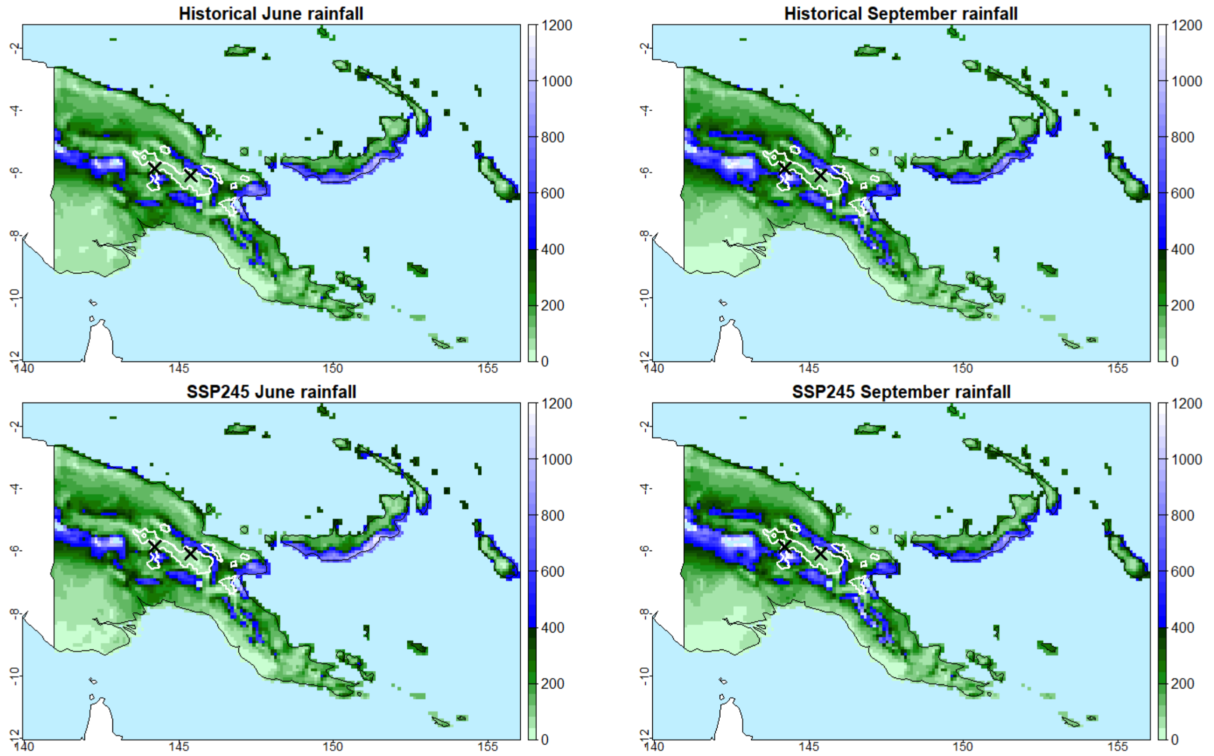

Figure 4: Historical and projected rainfall (mm) in PNG for June and September[5]

Despite the extensive climate modelling to determine the effect of climate change on coffee systems (Gokavi and Kishor, 2020; Pham et al., 2019), there is very little information about how PNG production might be affected. Coffee production systems in PNG will be affected in a similar way to the main arabica coffee-producing regions of other countries, such as Brazil, Indonesia, and Colombia. However, due to the nature of these smallholder farming systems, the effects on livelihoods will be different.

Coffee smallholders in PNG are already observing changes in the climate and to their coffee systems and agricultural systems more broadly. Coffee farmers are reporting that higher altitude coffee plantings are now producing more coffee than they used to, and other plants are also growing faster. Farmers have also observed that rainfall has become less predictable and is falling at what have previously been dry times. This has

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[5] The historical monthly rainfall data for June and September are shown in the top maps, with projected rainfall for June and September are shown in the bottom maps. Green shades indicate rainfall of less than 400 mm per month, while blue shades represent rainfall above 400 mm per month. These maps illustrate areas of lower and higher rainfall in PNG. The white outline indicates the region of significant arabica production.

either extended flowering or caused flowering to occur sporadically throughout the year. Farmers also report longer dry periods without significant rain.[6]

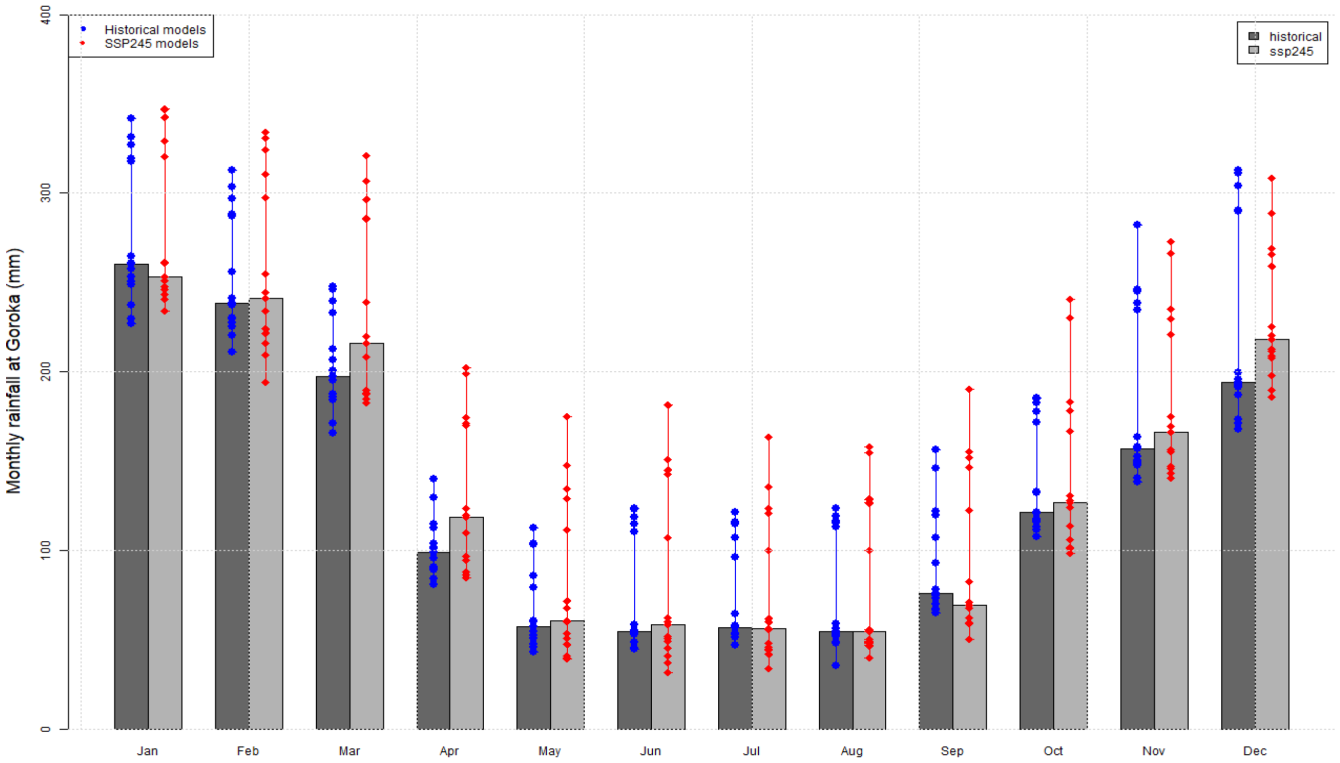

Figure 5: Monthly modelled rainfall for the historical period (1980 to 2010) and under an intermediate climate scenario (SSP2-4.5) for Goroka[7]

Coffee berry borer (CBB) was first detected in PNG in 2017, so it is not possible to determine the effects of climate change on the distribution or prevalence of this pest in the country. Nevertheless, a warming climate is likely to increase the number of CBB, as farmers report greater infestation levels in warmer areas. The effect of coffee leaf rust (CLR) will also need to be considered as climate projections infer increased temperature at higher altitudes, which will lead to a greater pest incidence. Coffee leaf

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[6] Schmidt *et al.*, 2024 report that 54% of households surveyed in the highland growing region reported having drought or irregular rain during the last five years.

[7] The grey bars show the modelled median historical (left, darker grey) and future (right, lighter grey) rainfall according to the models used in this study (modelled rainfall was used due to a lack of observational data). There is uncertainty associated with all rainfall findings. Not all climate models agree on historical and future rainfall. The range of values from the 15 underlying global climate model (GCM) is shown in blue for historical data and red for future projections. In general, the data used for this study comprises five 'wet' models (with higher average rainfall values) and ten 'less wet' models (with lower average rainfall values).

rust was detected in the PNG highlands in 1986 and spread rapidly, with the greatest effect in low altitude arabica areas (Bourke, 2018). Coffee leaf rust has had minimal effect in the main arabica coffee producing regions at 1400–1800 m, however, the temperature increases expected in these areas, particularly increases to minimum temperatures, could encourage CLR into the higher altitude areas. This means some new management strategies will be needed to help control this fungus in these areas (Bourke, 2018; see Brown et al., 1995).

Understanding of climate-related risks in PNG is hindered by both the lack of studies on localised historical and future climate changes and the limited data on many aspects of social vulnerability (Curry et al., 2017; Schmidt et al., 2024). The climate projections and likely effects on coffee production are summarised in Table 2.

Table 2. Summary of expected climate projections for PNG and effects on coffee production[8]

	Summary of climate projections and their effects on coffee
Climate projections	• By the 2050s, annual mean temperatures are expected to rise by 1 °C – 2 °C across the nation. This includes the highlands arabica coffee producing region. • Rainfall projections are uncertain; some models show increases in rainfall during March to June.
Effects on coffee production	• Decline in yield and quality due to temperature rise, pests (e.g. coffee bean borer, CBB), and diseases (e.g. coffee leaf rust). • CBB infestations are expected to increase and be more enduring because multiple flowering periods will cause no definitive crop break to suppress numbers. • Coffee leaf rust incidences are expected to increase and occur at higher elevations than it has occurred historically. • Increased drought frequency and rainfall variability. • Suitability may improve at higher altitudes (>2,100 m) but decline at lower altitudes (<1,000 m) due to higher temperatures, making it less suitable for coffee production. • Delayed, extended or increased flowering periods during the season. • PNG may have positive suitability changes for plant growth and fruit development, but must manage indirect effects (e.g. pests, extreme weather such as intense storm surges and droughts).

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[8] Based on Queensland Government's QldFCP-2 future projections dataset, which contains 15 global climate models, and report on the mean temperature and rainfall over the ensemble of models for the intermediate emissions scenario, SSP2-4.5.

6. Climate adaptation options for PNG coffee production

Worldwide, researchers are collaborating with coffee growers to identify adaptation options, some of which may apply to PNG coffee systems. Some options include adjusting the shade tree configuration, improving irrigation practices, implementing organic amendments such as cover crops, changing growing locations and planting new varieties. The CIC in PNG has also been exploring using deep-rooting rootstocks, adjusting shade tree species and planting densities, planting cover crops, and incorporating biochar or mulch. Promoting coffee agroforestry systems has emerged as a key approach. Adaptation approaches need to consider both short-term shocks (extreme weather) and long-term incremental changes (rising temperatures). Understanding how livelihood and household structures interact with the coffee system is also important (Rahn et al., 2025).

Adaptation options that could be suitable for smallholder coffee gardens fit into five broad categories:

- Improving coffee garden management
- Diversifying income
- Planting climate-resilient coffee varieties
- Changing location of coffee gardens
- Transitioning out of coffee

6.1 Improving coffee garden management

Improving coffee garden management practices is an important strategy to mitigate the effects of changing climatic conditions. These practices include improving shade and shade management, pruning, and managing soil moisture and nutrients, including using mulch and cover crops. Many of these are existing recommended practices for which adoption levels are low. Climate change makes the adoption of these practices increasingly important.

6.1.1 Shade management

Shade trees are crucial in coffee systems, regulating the microclimate in the coffee garden and enhancing soil health and biodiversity (Bosselmann et al., 2009). The success of shade trees used in coffee plantings for improving yield and quality depend on species selection, density, and management (Piato et al., 2020). Over-shading can reduce photosynthesis and lower yields, while under-shading might not provide sufficient protection from heat and drought. The amount of shade also influences the effect of pests and diseases on coffee (Schroth et al., 2000; Vega et al., 2015).

Changing the species and adjusting the density of shade trees could be a practical option to reduce the effects of rising temperatures, especially in lower altitude growing areas. Globally a diverse range of shade species is used. Common species include *Inga edulis* in Latin America, *Grevillea robusta* in East Africa, and *Albizia* spp. in Southeast Asia and the Pacific. These trees are selected for their ability to fix nitrogen, provide organic matter through leaf litter, and offer partial shade that reduces heat stress on coffee plants. Having shade trees in a coffee garden can reduce ambient temperatures by between 2 °C and 4 °C (Bracken et al., 2023). Additionally, shade trees help buffer against temperature fluctuation, variable rainfall and reduce evapotranspiration, which is increasingly important under changing climate conditions. Shade trees can also help to control soil moisture and potentially reduce the risk of soil erosion, thus providing a basis for soil conservation measures (Blanco Sepúlveda and Aguilar Carrillo, 2015).

A recent meta-analysis highlighted that moderate shade levels can improve bean size and uniformity, extend the ripening period, and improve cup quality by slowing maturation (Piato et al., 2020). Research from Colombia and Ethiopia showed that optimal shade levels, typically around 30–50% canopy cover, can lead to higher yields and better sensory profiles, including increased sweetness. In PNG, improving shading and integrating suitable species could offer similar benefits, especially in highland regions where temperature fluctuations and rainfall variability affect coffee performance.

Plate 2. Coffee shaded by *Casuarina oligodon*, Korofeigu area. (Source: Tim Sharp, Curtin University)

Having shade trees is common in PNG, with smallholder farmers often using *Casuarina oligodon* and *Albizia* species in coffee gardens (Plate 2). Both these species fix nitrogen, cycle nutrients and provide deep leaf litter, which improves soil fertility; the litter also helps suppress weeds (Curry et al., 2023b; Tilden et al., 2024). Shade trees require additional water, but as this is mainly sourced from the deeper soil layers, the water supply to the coffee trees is not compromised (Lin, 2007).

Several other species of shade trees are planted with less frequency, including *Leucaena leucocephala, Eucalyptus* sp.*,* bamboo *(Bambusa* sp.*), Schleinitzia novo-guineensis, Limbum (Hydriastele costata*), *Castanopsis* sp., *Pinus* sp.[9], *Araucaria* sp., and *Lithocarpus* sp., as well as a range of fruit and nut tree species (Section 8.2.1).

Additionally, shade trees increase biodiversity, which can reduce the incidence of pests, such as CBB (Jaramillo et al., 2019). They also provide wind protection and decrease

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[9] *Pinus* sp. is also being used as a shade tree in some areas. Although not N-fixing, it has a very deep tap root allowing it to access water at depth without competing for moisture with the coffee trees, and it can also tolerate stony soil (B. Apis, pers. comm. 2025). Clove trees (*Syzygium aromaticum*) are being grown successfully as shade trees in coffee in Timor-Leste and may be another shade tree option for farmers (Thomas and Curry 2025).

frost risk by influencing microclimatic factors (Koutoules et al., 2020). Shade trees also protect coffee trees from hail damage, as observed at a CIC trial site in Okapa in 2025. However, it is essential to balance the competition between coffee and shade trees for nutrients, water, and light with appropriate pruning and species selection (Gomes et al., 2020), which includes planting shade trees with root systems deeper than coffee root systems.[10] The CIC in PNG observed that in drier areas, Albizia shade trees are more productive, while Casuarina are better suited to wetter areas (Curry et al., 2023b; B Apis, personal communication, 2025). In the Simbu growing region, a shade tree that is more suited to rocky, mountain soil at the higher altitudes will need to be recommended. CIC have already started to work with the PNG Forestry Authority in trialling some of their species that may be suitable for these conditions (B Apis and E Kiup, personal communication, 2025).

6.1.2 Coffee tree pruning and rehabilitation

Effective pruning strategies will be an important climate change adaptation. Regular maintenance pruning and rehabilitative pruning removes dead and unproductive wood, promotes new growth and the efficient use of nutrients, prevents overbearing dieback and root dieback and in general encourages growth of a healthy productive coffee tree (Aroga et al., 2023). Pruning also helps manage pests and diseases. Pruning improves airflow and so reduces humidity creating an environment less suited to coffee leaf rust and CBB. Pruning also reduces CBB habitat (Newton et al., 2023).

Implementing strategic pruning and managing organic residue in coffee gardens could also offer smallholder farmers valuable adaptation pathways to improve soil health. Incorporating pruned material and leaf litter into the garden floor, rather than burning or removing it, promotes the gradual decomposition of organic matter, improving nutrients such as carbon in the soil. However, the breakdown process might reduce N availability in the short term for the coffee trees, as the C:N ratio of the prunings is relatively high. A study by Youkhana and Idol (2009) found that incorporating pruning residues in coffee plantations increased soil carbon and nitrogen in the top 200 mm by 10.8 t/ha and

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[10] Eucalypts, for instance, compete with coffee for water. Bamboo often appears in coffee gardens and is used for fencing and weaved for house walling, however, it can create overshading and has an extensive root system that competes with the coffee trees for water and nutrients.

2.12 t/ha, respectively, compared to a decline in the control. The shade trees in the coffee garden or plantation could also be maintained by pruning. In a study on the coffee shade tree *Erythrina poeppigiana*, pruning residues in a Costa Rican organic coffee system helped maintain or increase soil organic matter and nutrient availability, particularly near shade trees (Payan Zelaya, 2005).

The decomposition of woody residues from pruning helps nutrient cycling by slowly releasing nitrogen, phosphorus, and potassium, reducing the need for synthetic fertilisers. However, the effectiveness of this strategy depends on several factors, including tree species, pruning frequency, residue size, and soil conditions. These findings underscore the importance of integrating pruning and residue management into climate-smart coffee production systems.

6.1.3 Soil moisture and nutrient management

Effectively managing soil nutrients and water is essential for sustaining coffee production in smallholder gardens, particularly with climate variability and increasing drought risk.

Managing soil moisture

Due to the increased variation in rainfall and drought conditions expected with climate change, improving access to water can ensure resilience in coffee systems. In major coffee-producing countries such as Brazil, growers are adopting precision irrigation methods, including drip and micro-sprinkler systems. These enable water to be delivered directly to the root zone, minimising waste, reducing run-off and soil erosion (Guo and Li, 2024). These precision irrigation methods are combined with digital tools, such as soil moisture probes and weather forecasting apps, to help with irrigation scheduling and reduce water stress during critical growth stages. Practices that reduce water stress in coffee trees (Rahn et al., 2014), particularly during critical periods such as flowering, will decrease the frequency of flowering periods and ultimately increase harvests (Baca et al., 2014). Single harvests are important for mechanical harvesting and improve efficiency in large plantation settings, however, a highly concentrated harvesting period is less necessary for smallholders.

In PNG, where coffee farmers have low rates of reinvestment in their coffee gardens, it is likely that very few will adopt high-tech and costly irrigation monitoring. This has been observed by the CIC, with low levels of adoption of irrigation systems. A more suitable option to reduce water stress would include introducing more consistent mulching practices, which can help retain soil moisture and suppress weeds. This can also reduce evapotranspiration and improve microclimates, making coffee gardens more resilient to dry conditions.

Managing the garden floor

Cover crops are close-growing crops that can protect and improve the soil, increase nutrient turnover and provide the soil with resilience to climate stressors such as high temperature and heavy rainfall (Demir et al., 2019). In coffee regions around the world, adding grasses or legumes as a cover crop in plantations or gardens has become popular for improving soil health, reducing erosion, and reducing reliance on synthetic fertiliser (Ndiritu, 2022). Some studies have investigated incorporating leguminous cover crops to reduce nitrogen fertiliser applications and decrease nitrous oxide (N_2O) emissions, while also enhancing soil organic carbon (Zhang et al., 2024). Demir et al. (2019) found increased total nitrogen, organic matter and yield in an apricot orchard with grass cover crops, 500 mm away from the tree. These findings suggest that integrating cover crops into coffee plantations could be a practical and effective strategy for improving soil fertility and climate resilience.

The CIC has been experimenting with the use of cover crops, focused on improving nutrient use and soil fertility in smallholder coffee and food garden systems (Plate 3). They found that integrating leguminous cover crops, such as *Centrosema pubescens* and *Pueraria phaseoloides*, significantly enhanced soil nitrogen levels and organic matter content in coffee gardens. These species were effective in fixing atmospheric nitrogen, contributing to improved soil structure and moisture retention. Cover crops reduced weed pressure and erosion, which are common challenges in PNG's steep, high-rainfall coffee-growing regions.

Plate 3. Lima bean growing as part of CIC cover crop trial at Aiyura (Source: Barth Apis, CIC)

Integrating cover crops in the tree line and inter-rows can improve climate resilience of coffee gardens by reducing weed competition and decreasing the need for herbicide use, as well as improving soil moisture and health. While herbicides effectively reduce competition beneath coffee trees, in the tropical environments in which coffee is typically grown, they heighten the risk of soil erosion and degradation. The presence of bare earth along the tree lines exacerbates these issues, ultimately contributing to reduced coffee yields and increased need for nutrient inputs.

Few PNG coffee farmers have incorporated cover crops in their coffee gardens, but these improvements could be achieved with minimal inputs such as extra fertiliser, making them highly suitable for smallholder coffee gardens. There are also opportunities to manage nutrient flows between coffee and food gardens, which are often interlinked in PNG farming systems. Therefore, nutrient depletion in food gardens could be mitigated by recycling organic residues and implementing crop rotations that incorporate legumes. This has created a strong case for using locally adapted, low-cost organic amendments to help smallholder coffee systems adapt to climate change.

Pinto peanut (*Arachis pintoi*) is used by PNG smallholder coffee farmers as it can smother weeds, is short and can withstand up to 60% shade (E Kiup, personal communications, 2025).

Using organic inputs in nutrient management

When coffee cherries are harvested, approximately 15 kg N/ha and 17 kg K/ha are exported from the coffee garden (Kiup et al., 2025), with 50% of the N and 28% of the K in the pulp of the cherries. These valuable nutrients in the pulp can be recycled by returning them to the coffee garden to replenish some of the nutrients lost in the cherry (or they could be used on food gardens). It is better to use fresh pulp, as any delay in its application will result in significant leaching of nutrients, particularly potassium. However, fresh pulp is acidic and can lower the soil pH, so it should be applied in small quantities and spread one meter away from the coffee tree base (or following the drip line) to avoid damage from the heat that is emitted during decomposition (Kiup et al., 2025). A thin layer of pulp spread around the base of coffee trees will provide nutrients and mulch, promoting moisture retention and weed suppression. If the cherry is pulped in the coffee garden, spreading the pulp may not be so difficult; however, if pulping occurs at a distance from the coffee garden, an option is to compost it, making it lighter and more manageable. The risk with composting is that nutrients can be lost through leaching, so it is essential that the composting process is managed correctly. Coffee parchment skin, a waste product of processing parchment to green bean, is also a suitable mulch. The parchment skin can be obtained from coffee factories.

6.1.4 Other management practices

Around the world, other management practices to alleviate the effects of climate change on coffee production have also been trialled. Protective covers, particularly in the form of shade structures, are becoming more common in agriculture to protect crops from extreme rainfall, heat, and insect damage. In the major growing regions worldwide, protective covers are being increasingly adopted to improve the protection of nursery seedlings (Morais et al., 2004). For mature coffee production, they are seldom used, but as a climate-sensitive crop, there could be an opportunity to provide more security to yield and quality by adopting them. As protective covers provide shade, coffee could mimic its natural growth habitat in these systems, which could improve bean size and uniform ripening. Establishing protective covers would require a significant financial investment.

6.2 Diversifying incomes

6.2.1 Secondary income, shade and fruit trees

Planting trees that provide alternative income sources – in addition to providing other benefits of shade trees including microclimate regulation, weather protection, and organic mulch from decomposing leaf litter – is an important potential climate adaptation approach for smallholder coffee farmers. Secondary income fruit trees that have been successfully intercropped with coffee include citrus, banana, avocado, mango, macadamia and other tropical tree crops. In Africa and South America, intercropping coffee with bananas and macauba has provided growers with more income than standard monoculture coffee gardens (Pham et al., 2019). These systems have also reduced air temperature and direct solar radiation, which could be beneficial in lower-altitude areas where temperatures are expected to increase (Moreira et al., 2018). In Rwanda, Smith-Dumont et al. (2019) recorded 35 tree species within and surrounding coffee gardens, and an average of 4.6 different fruit species per farm. In Guatemala and Peru, Rice (2018) has reported that 19% and 28% of the value derived from coffee agroforestry systems was from shade tree products, respectively. Within these systems, fruit contributes on average of 10% of the value of the coffee system; for some farmers it represented over 40% of the value (Rice, 2011). Davis et al. (2019) reported similar findings from Jamaica. Shade trees can also provide income from the sale of timber and firewood (Rice, 2008) (Plate 4).

Plate 4. Casuarina shade tree harvested for timber and firewood, Makia (EHP), 2025. (Source: Tim Sharp, Curtin University)

Intercropping of fruit trees and other multipurpose shade trees is well established in PNG coffee systems (see sections 3 and 8.2), although smallholders could be supported to improve the benefits from and ensure the sustainability of these systems. Recently, coffee farmers in PNG, responding to the opportunity created by a changing climate, have begun experimenting with intercropping cocoa and vanilla with arabica coffee (see also Keane et al., 2021). Cocoa and vanilla have historically only been grown at lower elevations. During fieldwork, cocoa was observed, and farmers reported fruiting, at approximately 1,500 m above sea level. Farmers were observed interplanting bananas and taro to manage soil moisture and soil structure to benefit their coffee plants. Farmers were also seen interplanting and managing shade levels in their coffee to maintain food security during seasonal dry periods. The CIC have observed that farmers who grow coffee are often willing to try strategies that can potentially add economic value to the system. Some innovative farmers are already trialling expanded intercropping of their coffee with avocado, guava and citrus.

Despite the known benefits and opportunities of intercropping with secondary income trees or adjusting current shade tree densities, careful consideration of resource competition and light interception must be modelled and tested in field experiments. Moreira et al. (2018) found that shade trees planted too close to coffee can significantly reduce yield through competition for soil moisture. In PNG, minimal inputs already compromise coffee yields, and further constraints could severely impact production.

6.2.2 Intercropping of vegetables and other non-tree crops

Vegetables planted in the inter-rows of coffee trees can improve soil health, reduce erosion, and control weeds. Many different vegetable types can be used; however, careful selection based on growing conditions, market prices and demand will be crucial. Coffee farmers in Rwanda use a polyculture system, where coffee is intercropped with beans, tomatoes, sweet potatoes, yams, cassava, and soya beans (Harelimana et al., 2024). In addition to a more profitable income, these farmers have reduced infestations of coffee aphids, which are more prevalent in coffee monocultures than in intercropped vegetable systems (Harelimana et al., 2024).

In PNG, vegetable production for domestic markets is a major economic activity in the highlands, and intercropping is common, although intensity varies greatly. Fertilised cabbages can be successfully cultivated under coffee trees in PNG without compromising coffee yield (Curry et al., 2024; Plate 5). The practice also contributed to better soil health through organic composting and reduced erosion (Curry et al., 2024). Intercropping is most valuable in villages with limited land. The opportunities that intercropping presents in improving coffee systems should be further explored.

Plate 5. Cabbage intercropped under coffee, Asaro, EHP, 2019. (Source: Tim Sharp, Curtin University)

6.3 Planting climate-resilient coffee varieties

Coffee researchers are exploring the use of climate-resilient coffee varieties as an option to help safeguard coffee production. As discussed, traditional arabica varieties are vulnerable to rising temperatures, and increased pests and diseases (Van der Vossen et al., 2015). An International Multilocation Variety Trial (IMLVT), led by World Coffee Research, is evaluating 31 coffee varieties in multiple countries to identify those best suited to future climate conditions. These trials will provide critical data on how different genotypes respond to environmental stressors, helping guide variety selection for specific regions. The CIC are the research lead for this project in PNG.

Using different coffee varieties to adapt to climate change is a longer-term strategy, considering a coffee garden can be used for up to 50 years. This requires validating current and potential varieties at different altitudes, followed by breeding any new varieties suited to higher temperatures (Ovalle-Rivera et al., 2015) and changes in rainfall and patterns. Additionally, when developing new varieties, susceptibility to biotic stress, an indirect effect of climate change (Van der Vossen et al., 2015), must be considered. Developing and investing in new varieties in PNG will require significant government or industry investment in selecting, testing, and importing varieties from other countries.

A shift from arabica to robusta coffee varieties could also be considered as an adaptation option due to the projected decline in suitable growing conditions for arabica coffee. Robusta has greater tolerance than arabica to higher temperatures, certain pests and diseases (notably coffee leaf rust), and variable rainfall (Läderach et al., 2017; Merga and Alemayehu, 2019). Although traditionally viewed as inferior in flavour, robusta (*Coffea canephora*) is gaining attention for its resilience and reduced input requirements such as water and fertiliser. In Vietnam, reduced irrigation did not significantly compromise yield or quality in robusta production (Byrareddy et al., 2020), making it a viable alternative for lower altitude regions and changing climatic conditions. Existing research on coffee production and adaptation primarily focuses on arabica production, despite robusta accounting for approximately 40% of global output (Pham et al., 2019). Given the opportunity to use this variety as an adaptation option due to the decreasing bioclimatic suitability for arabica, further research on its production would be beneficial. Although it is very popular in Asian coffee regions, the suitability of robusta in PNG is not well understood.

Another breeding opportunity could involve developing deeper-rooting coffee varieties, which could improve nutrient acquisition and drought tolerance, offering further resilience in areas with water stress and soil degradation. By investing in breeding programs and variety trials, PNG can build a more robust and climate-adaptive coffee sector with enhanced productivity and sustainability.

6.4 Changing location of coffee gardens

Adjusting the location and orientation of coffee gardens is a practical adaptation strategy to mitigate the effects of climate change. Projections for PNG suggest that climate change is likely to for some locations reduce their suitability for coffee production, whereas in other locations suitability for coffee is likely to improve, depending largely on altitude and rising temperatures. Coffee grown within 5–10° of the equator below 1,000 m is unlikely to remain viable by the 2050s (Ovalle-Rivera et al., 2015). Shifting coffee gardens to higher altitudes along adjacent slopes, where cooler temperatures might offer more optimal growing conditions, could be a viable option for PNG growers. When planting new gardens, growers should be encouraged to avoid planting new coffee gardens on west-facing slopes to reduce exposure to intense afternoon sun, which can lower coffee quality and yield. The CIC in PNG has reported that lower-altitude regions are already having reduced yield and quality due to warmer temperatures. Therefore, the focus for the CIC now is adaptation in lower altitudes, and best practice growing in higher altitudes (B Apis, personal communication, 2025).

Changing location could be a longer-term strategy for mitigating the effects of climate change on coffee production, provided higher locations are available for planting new coffee gardens or a more suitable microclimate can be found nearby at similar altitudes. Moving to different locations might be limited by a lack of open land in these higher, remote areas or because the more mountainous areas could be too steep for production. Globally, relocating coffee production to cooler, higher altitudes has been recommended by several research studies (Pham et al., 2019). However, moving into these areas could degrade native forests (Rahn et al., 2025) and cause customary land tenure disputes.

6.5 Transitioning away from coffee

For coffee farmers most vulnerable to the effects of climate change, a gradual transition away from coffee may be the most appropriate adaptation measure. The suitability of this option will be shaped by the effects of climate change on the farming systems, but also the capacity of the farmers to adopt other adaptation measures and the existence of alternative income sources that may support a pathway away from coffee (Section 8.5). Most coffee-producing areas in PNG are, however, likely to remain suitable for coffee in 2050, and in these areas, adaptation strategies that retain coffee as part of a broader farming and livelihood system should be prioritised.

7. PNG smallholder coffee systems and factors affecting adoption of climate adaptation strategies

Several factors influence smallholder adoption of climate adaptations and of innovations more generally – whether technological or changed practices. These include: socio-economic factors (age, gender, education, household composition, and household wealth); access to assets (land, labour, technology, markets, capital); institutional and political factors (government policy, market structures); socio-cultural factors (values, beliefs, social structures); and cognitive and psychological factors (trust, risk perception) (Dang et al., 2019). This report focuses specifically on the socio-cultural factors that shape adoption in smallholder coffee systems in PNG, and smallholders more broadly, to identify key factors to help us understand the suitability of different climate adaptation options for PNG smallholders.

Coffee farmers globally are adapting their farming systems in response to current and future changes in the climate, and significant research is being directed to make coffee systems more climate resilient. Some of these approaches will be suitable for PNG farmers while others will not. Some climate adaptation approaches come with substantial risks and costs for PNG smallholders. The key socio-cultural factors that will shape smallholder adoption of climate adaptations include:

- Diversity of livelihood activities
- Livelihood priorities
- Sensitivity to returns to labour
- Low-input production strategies
- Gendered division of household labour and household decision making
- Labour availability constraints
- Land ownership and access

7.1 Diversity of livelihood activities

The broader livelihood system within which coffee farming occurs (Figure 6) will profoundly influence the adoption of climate adaptation practices by smallholder coffee farming families. Smallholder coffee farmers are heavily involved in food production for household consumption, with most calories consumed produced by the household itself (Bourke, 2019). Time invested in subsistence production is higher in more remote areas, but even in accessible areas, food gardening for the household is a major activity (Koczberski et al., 2021a).

Smallholder coffee farming households typically have a range of income-earning activities (Koczberski et al., 2023a). In rural communities close to urban centres, people have relatively good access to urban marketplaces, waged-employment opportunities, and small-scale trading opportunities. In these areas, there is greater diversity of income sources than in remote coffee-growing locations, and there are generally more income sources in each household (Curry et al., 2017). In these accessible areas, for many households, coffee is not the main source of income. In more remote parts of the highlands, coffee is the dominant income source for most households, although subsistence production contributes more to meeting household needs.

Like many other farming families in PNG and the Pacific, smallholder coffee households have tended to prioritise diversification and flexibility over specialisation: minimising risks rather than seeking to maximise income. By maintaining diverse livelihoods, including multiple income sources, coffee smallholders reduce their vulnerability to shocks, including from pests and diseases and market volatility. Diversification was vital to PNG cocoa farming households' ability to cope with significantly reduced incomes following the cocoa pod borer's arrival (Curry et al., 2015; Ndrewou, 2023). It also enabled oil palm smallholders to manage growing population and land pressures (Nake et al., 2025). Livelihood diversity also helped farmers buffer the effects of changing markets (Sharp et al., 2022) and adjust their labour across a range of crops and other livelihood activities in response to changing returns to labour (Section 7.3).

In addition to earning an income and producing food for household consumption, smallholder households commit time to daily domestic activities and to more intermittent work such as house building and garden fencing. Smallholders also spend significant amounts of time in socio-cultural activities. These include ceremonial activities and exchanges surrounding marriage, death, and other life-cycle events (e.g. graduations), as well as resolving interpersonal, intra-group and inter-group conflict. People are also frequently involved in church activities. Visits to relatives and friends are common and help reinforce social relations of dependence, support and obligation. People engage in these networks because they value these relationships and the way of life (Koczberski et al., 2023a). These networks also contribute to household resilience. In the absence of a welfare state, people rely on these social and kin relationships to provide a level of insurance and security.

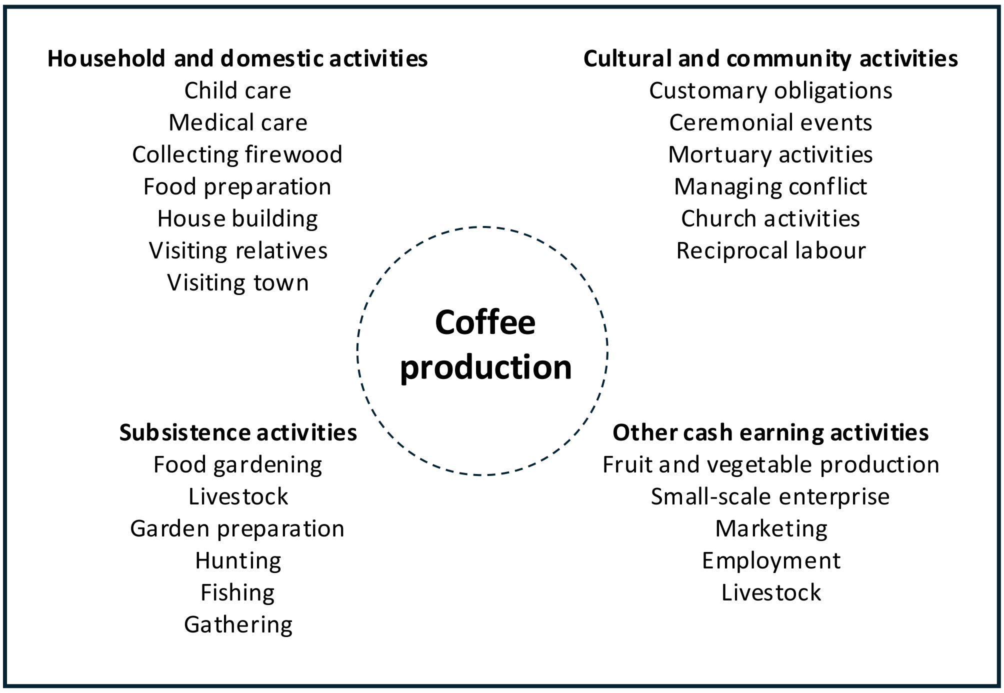

Figure 6: Smallholder coffee farming livelihood system: the diverse livelihood activities that influence coffee production
(Source: adapted from Koczberski et al., 2023a)

In considering climate adaptation, it is important to recognise the time and labour commitments of smallholders to a range of livelihood activities other than coffee production: namely, subsistence production, other income-earning activities, domestic and caring responsibilities, and social and cultural activities. Together they are vital in their role in building household resilience and reducing vulnerability. Adaptation strategies that require significant additional labour at the expense of time invested in nurturing social relations may be resisted and could undermine resilience.

7.2 Livelihood priorities

Farmer adoption of climate adaptation strategies will also be influenced by how they align with indigenous socio-cultural and economic values and livelihood goals (Curry et al., 2021). The role of the socio-cultural context, and livelihoods beyond the target crop, in determining adoption is often ignored or poorly understood. Coffee farming families are not full-time coffee farmers, and generally do not depend exclusively on coffee income to meet household needs; other activities are frequently prioritised over coffee work. Even when managing smallholder coffee gardens, coffee production may only be one of several goals. Coffee gardens are also managed to: provide household food production, including during seasonal dry periods; provide a range of other resources (fibre, firewood, medicines); moderate income over time; provide a low-input source of income; minimise risk; maintain social relationships; and manage customary land. These livelihood priorities will influence the readiness of coffee farming families to adopt different climate adaptation practices.

Adopting new technology, including organisational innovations, may be more attractive to smallholders if they help resolve a social ‘problem’ (Curry et al., 2021). This was evident with the eager adoption of the ‘Mama Lus Frut’ scheme among female oil palm smallholders in PNG in the late 1990s. This scheme paid women separately from their husbands for their collection of oil palm fruitlets (Koczberski et al., 2022; Nake et al., 2025). At the time, inadequately paying women for collecting loose fruit on their household holdings led to fruit being under-harvested. This was a major production loss for the oil palm companies. It also created widespread intra-household tensions over the fortnightly oil palm income disbursement, which male household heads controlled. The scheme has been highly successful, and is still running 30 years on, largely because it reduced intra-household conflict over income distribution and empowered women in oil palm production.

7.3 Sensitivity to returns to labour

Rural people in PNG are highly responsive to returns to labour (Allen et al., 2009) and this affects the adoption of innovations including technology, new crops, and new practices. Returns to labour refers to the money earned (or non-monetary benefit) relative to the work invested, in this case to produce a crop. The returns to labour are affected by the price growers receive, the costs of production and accessing markets, and the efficiency of labour.

The returns to labour for smallholders are most visibly influenced by fluctuations in international commodity prices. In PNG it is common in all the major cash crops (coffee, oil palm, cocoa, and copra) for smallholders to adjust their labour inputs in response to prices. When prices are high (as they are for coffee at the time of writing), smallholder harvesting rates increase as does block maintenance, and when prices decline, producers will frequently carry out minimal block maintenance and underharvesting is common (Bourke, 2022).

The relative returns to labour of different economic activities are important. It is common for smallholders to shift labour to activities they see offer improved returns on their labour. This is particularly so in accessible rural areas, where there is greater diversity of income earning activities than remote locations (Koczberski et al., 2021b; Benediktsson, 2002:189-91). In accessible parts of the highlands, smallholders commonly shift their labour to fresh food production for domestic markets when coffee prices are low, only to renew interest in coffee when prices again improve. In less accessible locations where coffee is the only significant income source, smallholders commonly respond to declines in the returns to labour by reducing coffee garden maintenance, and reducing coffee harvesting to a level that meets their income needs, but are then reluctant to commit further labour.[11] Smallholders often have a target price, under which they will reduce their input and eventually stop production (Allen et

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[11] In remote locations, the returns to labour can be very low due to high transport costs.

al., 2009).[12] These responses to changes in relative returns to labour will have a significant influence on the adoption of climate adaptation measures.

Smallholders shift their labour in response to short-term price changes, but also in response to longer-term changes. Smallholders' real incomes from coffee production have declined since the 1990s, while the returns to labour for fresh food production have been substantially higher than for coffee (Sharp et al., 2022). In areas with strong commercial engagement in domestic fresh food markets, such as the Asaro and Ifiufa areas of the EHP, and in locations close to Mount Hagen, some farmers have uprooted their coffee trees to make way for sweet potato, carrots and cabbages among other marketable fresh foods (Plate 6).

Plate 6. Coffee trees uprooted to free up land for commercial vegetable production, Hagen Central (Western Highlands), 2018. (Source: Mike Bourke)

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[12] In the past, smallholders were probably more prepared to reduce their market engagement and fall back to subsistence production, however, today rural people have increasing needs and desires that can only be met with money, and so exit is likely less common.

Adoption of climate adaptation strategies will also depend on the gendered returns to labour, and the returns for different household members. In PNG, coffee (and other export commodity crops) is commonly regarded as belonging to men, and although women frequently contribute significant labour to coffee production, men generally control the distribution of the income earned. This has led many women, feeling inadequately remunerated, to withdraw their labour from coffee production in favour of growing food for local markets, an economic activity where women typically have greater control over the income earned (Koczberski and Curry, 2016; Curry et al., 2019; Sexton, 1986). In the 1990s, when returns to labour on coffee were substantially higher, Overfield (1998) showed that the inequitable gendered distribution of coffee income within households led to suboptimal investment of labour in the household. Even though the returns to labour on coffee were higher than for fresh food, they were not higher for women.

Prices have an obvious effect on the returns to labour; however, returns to labour can also be influenced by changes in labour efficiency. In East New Britain and East Sepik provinces, declines in labour efficiency due to the effects of cocoa pod borer led many farmers to abandon cocoa production (Curry et al., 2011; Ndrewou, 2023). Conversely, technology can help improved labour efficiency. For example, a trial of demucilager technology, which made coffee processing easier (as well as improving quality and price), encouraged interest in coffee among farmers (Curry et al., 2024; Kumie and Sharp, 2025).

Importantly, smallholder evaluation of relative returns to labour is not purely a monetary calculation, as smallholders also consider the non-monetary benefits they derive in terms of food security, and from the social economy. The climate adaptation options discussed in this report all require decisions about committing additional labour (and other inputs), and each has implications for the returns to smallholder labour.

7.4 Low-input production strategy

Most smallholder farmers of all the major export cash crops in PNG adopt a low-input production strategy (Curry et al., 2015). Smallholders typically minimise labour and capital inputs, and accept low yields. Smallholders are most interested in securing reasonable returns on labour, rather than returns per tree or unit of land (Finney, 1973; Curry et al., 2015). Minimal farm management is an enduring characteristic of smallholder coffee systems in PNG (Harding, 1988; Curry et al., 2017). Coffee garden maintenance is generally low, with trees rarely pruned. Stumping and replanting are often not done, resulting in many coffee trees being old and low yielding. Weeding may only be carried out during the coffee season to provide access to harvest (Grossman, 1984:186).

Despite the low coffee yields, a low-input production strategy enables smallholders to manage risk by maintaining diverse livelihoods and income sources. Volatile coffee prices also lead to smallholder uncertainty about whether they will ultimately benefit from their additional investments. A low-input approach is also a response to limited labour availability (discussed below), as well as limited access to capital due to the challenges of saving and securing credit for rural Papua New Guineans. This strategy also enables people to have strong participation in socio-cultural activities, which are highly valued (Koczberski et al., 2023).

The strong desire to maintain a low-input production strategy is evident among smallholder cocoa growers in PNG, and their responses to cocoa pod borer, which decimated cocoa yields. Smallholders were initially faced with a choice of either abandoning cocoa or adopting a much higher input approach. In the years following the arrival of cocoa pod borer, few farmers adopted the high-input approach, as most were unwilling to substantially reconfigure their livelihoods (Curry et al., 2015). The coffee industry in PNG currently faces a similar threat with the more recent arrival and spread of CBB. As with cocoa pod borer, successfully managing CBB will require high labour inputs, particularly harvesting labour.

Low-input production strategies also lead coffee smallholders in PNG to prefer tall coffee varieties over dwarf varieties as the tall varieties are hardier and more tolerant of low maintenance levels. Tall varieties are also perceived to be easier to harvest than the dwarf varieties which are planted at high densities (Curry et al., 2023c). Low-input production strategies also lead to low uptake of new technology and extension advice. The dominance of low-input strategies by smallholders means that climate adaptation measures requiring high labour or capital inputs will be unsuitable for most smallholders, and approaches requiring even moderate increases in inputs may be resisted.

7.5 Gendered division of labour and household decision-making

The gendered division of labour within households will affect the adoption of climate adaptation strategies. Coffee work is gendered, although importantly there is a lot of variation between households and between locations (see Grossman, 1984; Sexton, 1986; Overfield, 1998; Eves and Titus, 2020; Curry et al., 2021; Koczberski et al., 2021a). Tasks such as preparing land for new coffee holdings, digging drainage ditches, fencing and planting coffee are more commonly performed by men, who have a similar role in preparing land for food gardens. Weeding, and mulching if done, is usually a task in which women are more heavily involved and, again, women are typically responsible for this work in food gardening. Men are more likely to prune both coffee trees and shade trees (Sengere, 2016:140; Eves and Titus, 2020). Planting trees, because of their semi-permanence, is a means to strengthen claims to land so, within the highlands patrilineal land tenure systems, it is generally men who are permitted to plant, and hence own, coffee trees.

The whole household is generally involved in harvesting cherry, although women are frequently more involved, and particularly in the past this was seen as women's work. Women also contribute to inter-household labour exchanges during the peak season (Curry et al., 2021), and pick small amounts of cherry during the off-season to pay for immediate household needs.

Women's labour in coffee production is more concentrated within the main harvest. Men's labour in coffee is also more intensive during the flush, although, they also do maintenance tasks during the off-season (Curry et al., 2021; McKellar, 2024). Women contribute substantially more labour to food gardening, both for household consumption and sale, and to the marketing of that food (Curry et al., 2021; Sharp et al., 2022). As with coffee work, men are generally more involved in the heavy work of land preparation.

Despite women's significant role in household coffee production, men are more likely to have received training (UniQuest, 2013; Hamago, 2021). Women are often excluded due to their lower levels of education and heavy workloads. There is also a lack of female extension officers to work with women (Hamago, 2021). Successful climate adaptation will require extension approaches that engage and support both men and women and include both male and female extension officers. Such approaches need to be aware of existing gendered divisions of labour, but should also work to reconfigure these.

7.6 Labour availability constraints

The availability of labour is one of the most significant constraints on coffee production for coffee farming families (Curry et al., 2021). It is likely to be a primary factor influencing the willingness and capacity of smallholder coffee farming families to adopt climate adaptation strategies, particularly those related to managing the coffee garden. Constraints on labour include the absolute shortage of available labour, the inability to access available household labour due to reluctance among household members to contribute labour, and competing demands on labour from other livelihood activities (Curry et al., 2021). So, while smallholders may want to adopt climate adaptation strategies, labour availability might constrain their capacity to adopt.

Absolute shortages of labour are often shaped by the demographic profile of each farming family, particularly the number of household members of working age and available to work. Labour availability often changes throughout the different stages of life: couples with young children may face labour shortages, as do older households, whereas households with older children and young adult children generally have more potential sources of labour. Illness, and household members residing elsewhere for work or education, also effects labour availability (Curry et al., 2017).

Households, even without absolute shortages of labour, may still find it difficult to recruit the labour of household members. As mentioned above, women who are dissatisfied with the distribution of coffee income within the household are more likely to direct their labour away from coffee to activities where they have greater control over the income earned (Section 7.3). Older children and young adult children may also resist contributing labour when they do not see it being of benefit to them. Smallholder coffee farmers also often struggle to secure reciprocal labour contributions due to extended family members being increasingly reluctant to provide unpaid labour in activities directed at earning money (Inu, 2015). Most often it is female relatives that provide reciprocal labour. There is generally minimal use of hired labour to overcome labour shortages (Curry et al., 2021), although in some communities, migrants are an important source of labour and coffee farmers may invite groups of migrants to reside on their land to provide a source of paid labour.

Climate adaptation will be shaped by women's already high work burdens. In addition to significant contributions to household coffee production, and subsistence work, domestic and childcare duties fall more heavily upon women. Climate adaptation strategies that place additional work upon women may be resisted, or if adopted may inequitably effect women. Conversely, climate adaptation strategies that help to reduce women's workloads may be more readily adopted by women.

7.7 Land ownership and access

The ability and willingness of smallholders to adopt climate adaptation strategies will be shaped by the customary system of land tenure and access. Throughout the highlands, where most of PNG's arabica coffee is grown, land is controlled by patrilineal groups. This means that rights to land are established largely through male descent, from father to son. These groups are also patrilocal, meaning that upon marriage, women typically move to their husband's land. Women generally have usufruct rights to land, which they gain through their relations with men – primarily their husbands, but also their fathers, brothers, and sons (Strathern, 1979: Sexton, 1986; Inu, 2015).

Control over a particular area of land is established through the act of clearing it, digging ditches, and planting crops, and maintained through ongoing use of that land. Trees, as enduring markers of control over land, are then typically planted by men, or in their name. Women generally have good access to land to plant vegetables for home consumption and sale, however, their access to land to plant coffee (or other tree crops) is substantially more constrained. Some women do ‘own’ coffee trees (although not the land below) and women may be granted the right to harvest the coffee trees of another and be responsible for their management. These types of arrangements hinge on the support of a male relative (see Spark et al., 2021).

Land tenure systems are highly flexible. There are many instances of men residing on the land of their wife’s natal kin, of men who cannot trace descent to the clan on whose land they reside and farm, and of women controlling coffee plantings. However, departures from the ideological norms tend to weaken claims to land. In the context of limited land access, there is less security for those holding coffee on maternal land, or on their wives’ land. Importantly, the highlands region is culturally diverse, and there is variation in how land ownership and use are arranged.

Since colonisation, there has been a quasi-privatisation of land, and coffee has been central to this (Strathern, 1979; Sexton, 1986:61-2). Coffee, as a tree crop, occupies land for extended periods. Coffee may therefore be used to hold land, even with minimal maintenance, and creates a rigidity to land control.[13] Parents will often plant a coffee garden for their male children when they are young, encouraged by coffee ownership being a marker of status. Planting coffee throughout the highlands (primarily from the 1950s to early 1970s) has increased the total area of land under cultivation, and this, combined with population growth and demands for cash, has placed further pressure on land. In areas where land is scarce, this has encouraged private enclosure, and reduced flexibility and accommodation within the system (Brown et al., 1990). Where land is limited, or for land-short families, it can be difficult for young men to establish their own coffee plantings (Sengere, 2016).

Where climate adaptation strategies involve a change in land use, men are likely to be the primary decision-makers. Decisions regarding the long-term occupation of land or effect on land-based assets, may or may not include consultation or consideration of

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[13] People can hold rights to coffee (and other trees) without rights to the land below, however, the planting of coffee may still exclude others (Grossman, 1984: 100-101).

their wives, female kin, widows and divorced women now residing in their natal village. Adaptation practices will need to include strategies that aim to elicit women's voices and the long-term security of future generations. Strategies that require the coordination of multiple landholding groups will face additional challenges.

8. Evaluating climate adaptation options for PNG smallholders

In this section the appropriateness of several climate adaptation options, outlined in Section 6, are evaluated for the socio-cultural context of the PNG highlands. We draw on the discussion in Section 7 to assess the likely effect on the willingness and capacity of smallholders to adopt each of the strategies, and some of the risks and uncertainties related to them. The focus is on socio-cultural and socio-economic factors, including gender relations, labour availability, land tenure, and livelihood approaches and priorities. Many other factors motivate farmer innovation adoption and climate change adaptation, namely: education, access to resources and technology, farm characteristics, access to extension services, and perceptions of climate change. Additional factors also influence the suitability of the approaches, including institutional capacity, technological complexity and economic context (see Dang et al. 2019), but these are beyond the scope of the research objectives and are not covered in this report. This discussion focuses on smallholder farmers growing arabica coffee in the highlands. It does not cover the plantation sector, although there may be some relevance.

When assessing the suitability of different adaptation options and smallholders' capacity or willingness to implement them, we are mindful of the following:

1. Smallholder coffee farming families are diverse. They differ in their household composition, assets, livelihood priorities and approaches.
2. They grow coffee in different environments and over a wide altitudinal range, which will also modify the effects of climate change on their coffee systems.
3. Relatively moderate changes in climate may lead to much more significant effects in the context of PNG's low-input coffee systems.
4. Coffee farming families are already adapting their livelihoods and coffee systems in response to climate change and other factors including population growth and a changing economic environment.

This section examines the appropriateness of the following adaptation measures: changing coffee management strategies; diversifying livelihoods; planting climate resilient coffee varieties; and changing coffee garden locations.

8.1 Improving coffee garden management

- *Improve how shade and soil nutrients are managed, pruning and mulching can boost coffee health, yields, and climate resilience*
- *Improve pest and disease management, especially of CBB, will be critical to climate adaptation*
- *Adopting these practices is often constrained by labour shortages, costs, and limited farmer awareness*

Changes to coffee garden management practices to improve health and productivity, will be critical to climate adaptation. If smallholders wish to continue to produce coffee, they will have to commit more labour to managing shade trees, soil, and pests and diseases (notably CBB), pruning coffee trees, using mulch and cover crops, and rehabilitation practices. Smallholders will also need increased extension support.

8.1.1 Shade trees

Improving shade levels within coffee gardens will be a vital climate adaptation strategy. It aligns well with low-input smallholder coffee systems, although many farmers are not fully aware of shade's value in a changing climate. Most coffee in PNG is grown in shaded systems, and so the practice is familiar to coffee farmers. Farmers recognise the dominant shade tree, *Casuarina oligodon*, provides benefits as it has been used for centuries to manage soil fertility (Bourke, 1997). Farmers also recognise the role of shade trees within coffee gardens and adjacent forested areas in creating cooler microclimates. The ability of shade to reduce both labour and chemical inputs (e.g. use of glyphosate for weed control) in smallholder systems makes it particularly valuable (Curry et al., 2023b; Tilden et al., 2024).

Although most smallholder coffee plantings have shade trees (UniQuest, 2013), the level of shade is often suboptimal, either under-shaded or over-shaded, and varies within individual gardens where shade tree spacing is often irregular (Plate 7). Overshading occurs because the wrong shade trees have been grown, or they have not been maintained. Shade trees are often not pruned because it requires too much labour, and there is concern about the potential damage falling pruned branches can inflict on coffee trees. Some farmers may also be reluctant to remove and replant large established trees, including for cultural reasons.

Plate 7. Uneven shade coverage within a coffee garden, Eastern Highlands. (Source: Kingsten Okka/Tilden et al., 2024)

Under-shading occurs because shade trees have died, or have been removed for firewood or construction and not replaced. There is a high demand for casuarina for construction and firewood, and farmers need to be encouraged to replant when trees are removed. In some areas, declining shade levels may be linked with population growth, and associated demand for timber and firewood. The increased intensity of intercropping coffee with food crops in some locations will also discourage a return to shaded systems there. Farmers also remove shade trees to increase production, not realising this can lead to overbearing dieback without the import of additional nutrients.

Shade trees need to be pruned to maintain suitable shade levels for coffee productivity and pest and disease management. Due to lack of extension training many farmers are unaware of the best time to prune shade trees to enhance coffee yield and have limited understanding of the effect of shading on pests and diseases (Tilden et al., 2024), including those likely to be exacerbated under climate change.

Further, farmers require training in shade tree species selection (which will depend on an individual farmer's circumstances and location), shade tree spacing, optimum shade levels, and shade tree maintenance. Casuarina, for example, is not suited to drier areas, and it has a narrow canopy that can lead to under shading if not planted at the recommended density. *Albizia* sp. are large trees with a broad canopy. Pruning can be difficult due to their size, and when pruned the falling branches can damage the coffee trees.[14] This often results in overshading because of the reluctance to prune them. Due to labour shortages in coffee households, it is likely farmers would preference species that require minimal maintenance.

Extension training needs to educate farmers about the benefits of shade trees for suppressing weeds, maintaining soil fertility (particularly if they fix nitrogen), controlling pests and diseases, and in supporting coffee tree health. Extension should also emphasise how appropriate shading can reduce labour and capital inputs. Despite the

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[14] Paid labour can be used for some coffee management activities. It is likely not suited to shade tree pruning due to the risk of damaging the coffee trees and the risk of conflict due to this damage.

cost, household labour constraints mean that herbicide is currently widely used as a labour-saving technology (UniQuest, 2013; Koczberski et al., 2021b).[15]

Farmers should be encouraged to grow diverse shade trees to support the ecosystem and improve coffee system resilience.[16] Most coffee gardens in PNG already have some diversity of shade species, so farmers are likely to be amenable to enhancing diversity if they understand the benefits. Farmer concern about CBB may also support adoption, if the potential for shade and biodiversity to reduce the effect of the pest is emphasised. By supporting biodiversity, farmers who achieve certification for their coffee can also receive higher prices.

Shade trees can provide a secondary income such as from fruit and nut trees or trees that support honey production (see below).[17] There is also strong demand for timber and firewood, both for household use and for sale locally.

Shade species and management recommendations must be specific for individual areas. In seasonally dry areas, farmers use overshading as a strategy to cope with dry periods, having witnessed the effects of inadequate shading during the dry season. Using shade to maintain soil moisture and maintain a cooler microclimate during dry periods also helps food crops (including bananas and Xanthosoma) and household food security. Farmers use shade trees in different contexts. For example, *Albizia* sp. is used in poorer soil, and drier areas whereas casuarina requires better soil and can be used to reduce waterlogging. Banana, which is commonly grown as a temporary shade tree in immature coffee gardens, is also strategically used to improve soil structure to

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[15] A survey of coffee farmers in PNG found that herbicide was used by 72% of farmers (UniQuest, 2013:40). Herbicides were also among the most common purchases made by smallholder coffee farmers when credit was made available to them (Koczberski et al., 2021b:58).

[16] CIC officers have observed casuarina in parts of EHP and WHP damaged by a boring insect leading to high mortality. CIC entomologist, Jonah Aranka, identified the pest as an ambrosia beetle, likely from the *Xylosandrus* genus (Hulcr and Skelton, 2023). These attacks can signal underlying issues regarding general tree health and other compounding issues such as poor soil fertility and ambient temperature increase.

[17] Shade tree planting density is higher during the establishment phase of a new coffee garden when the shade trees are smaller. As the shade trees grow, the density can be reduced, and these trees can be sold or used for timber or firewood. Maintenance pruning of shade trees, as well as eventually the harvesting of mature trees, is also a source of timber and firewood, that can potentially provide a source of income. Higher density shade plantings can enhance carbon sequestration within the system, however, they require substantial labour to maintain pruning, and the likelihood is that this will not occur.

facilitate root growth and retain soil moisture. Some farmers prefer to plant the legume, *Leucaena leucocephala*[18], as a shade tree due to its smaller, more manageable size and better performance in some areas. Faster growing shade species such as *Leucaena leucocephala* can, however, demand higher and more regular labour.

Plate 8. Fruiting coffee tree under casuarina shade trees. (Source: Tim Sharp, Curtin University)

If seasonal shade tree pruning is timed correctly it can be used to stimulate and synchronise flowering and therefore fruit development (Plate 8). This has several benefits for smallholder farmers, which may encourage adoption. A more concentrated coffee season can improve harvest labour efficiency. Farmers can also concentrate their coffee labour to particular times of the year, reducing periods of competing labour demands. This will particularly benefit farmers involved in commercial food production. A more concentrated flush period also helps with seasonal coffee tree pruning, which

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[18] Leucaena leucocephala is commonly used as shade in robusta coffee gardens.

improves tree health. Shading can also reduce biennial variability of coffee yields (DaMatta et al., 2007), which can support income stability for smallholders. A more concentrated season also helps with managing CBB by breaking its life cycle. Farmers with very high losses due to CBB may be more likely to adopt this strategy.

Asynchronous flowering may, however, benefit households which are otherwise unable to provide sufficient labour to harvest the available crop during peak production periods. Some farmers may also prefer asynchronous flowering and harvesting to be spread over an extended period so that household income from coffee is also extended. This applies to households with limited income diversity beyond coffee. A less concentrated season may also benefit women's incomes from coffee. In the peak coffee season, households are more likely to process their coffee to parchment, which they stockpile and sell in a single large transaction – men typically control the income from these parchment sales. In contrast, in the shoulder season, it is common for smallholders, particularly women, to instead sell small amounts of coffee cherry to local buyers to meet immediate household needs (Sexton, 1986).

A less concentrated season is problematic for CBB management, as smallholders need to maintain regular weekly harvests over a longer period. It is likely that many households would struggle to maintain this, leading to periods of underharvesting. Thus, in lower elevation areas where CBB is a significant problem, there are strong benefits of shaded systems and seasonal shade maintenance.

Despite the advantages of growing shade trees in coffee gardens there is likely to be some reluctance to planting or replacing shade trees in areas of intensive intercropping. Intercropping can be a sustainable alternative to shaded systems if nutrient balances are well managed and there is no competition for water, light and nutrients.

For most smallholder farmers, improving how shade is managed is an effective climate adaptation measure that suits the low input production system. Extension services should help farmers with selecting trees and improving awareness of the benefits of maintaining shade trees, and research is needed to guide the sustainable incorporation multipurpose shade trees. More research is also required to understand how climate change will affect shade trees and in finding alternative shade tree species, particular trees that deliver multiple benefits to smallholders.[19]

8.1.2 Coffee tree pruning and rehabilitation

Implementing effective pruning strategies will be an important climate change adaptation for smallholders. The benefits of effective coffee tree pruning are often not fully understood and so this important task is often neglected (Curry et al., 2017).[20] Regular maintenance pruning and rehabilitative pruning removes dead and unproductive wood, promotes new growth and the efficient use of nutrients, prevents overbearing dieback and root dieback and in general encourages growth of a healthy productive coffee tree (Aroga et al., 2023). Pruning also contributes to CBB management by improving airflow, which reduces humidity creating an environment less suited to CBB, and through reducing CBB habitat (Newton et al., 2023). All these benefits will be especially important for keeping coffee gardens sustainable as the climate changes.

One of the main barriers to pruning is the high labour requirement (Section 7.6), as well as the delay between pruning labour and receipt of benefits, such as improved yields and income.

Farmers are also reluctant to prune because they see flowers and immature fruit on the trees as future income. This reluctance is exacerbated in gardens where changes in the climate and inadequate shading have led to continual flowering. There is even stronger reluctance to recycle prune and stump, due to a loss of income for up to two years. Supporting alternative income sources, including intercropping of coffee with other crops (Section 8.2), provides a strategy to mitigate income loss during garden rehabilitation or replanting. Staggering stumping or replanting of coffee gardens over

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[19] Rehabilitating coffee blocks at Aiyura may be an opportunity to trial different shade systems and their associated ecosystem services – in pest management, shade, and pollination – and planting trees in areas surrounding coffee gardens should also be considered. Trialling different species will provide an opportunity to evaluate their suitability to intercropping with coffee.

[20] Each season, coffee trees only produce cherries on new growth. Therefore, every year primary branches that have produced two crops should be removed otherwise the tree wastes valuable nutrients supporting unproductive wood. When the trees are six to seven years old production declines and the coffee trees require major pruning (recycle pruning) or stumping to rejuvenate growth.

several years is also a strategy to ensure farmers do not have years without a coffee harvest.

Having understorey intercrops may encourage maintenance pruning to increase light availability to the crop. Pruning is, however, generally carried out by men whereas intercropping of vegetables is more likely to be done by women, and this misalignment between who is doing the work and who derives benefit from that work may affect adoption.

Increasing coffee tree productivity by improving nutrient maintenance and CBB control may encourage farmers to adopt effective pruning practices. Extension messaging, however, has long emphasised the role of pruning in improving productivity, yet many farmers conduct only minimal and irregular pruning due to the constraints above. Successful adoption would likely require more intensive extension support, including repeated extension visits and demonstration gardens. Extension on pruning is likely to be more effective if integrated with strategies to support secondary income and income replacement during recycle pruning, and with strategies that overcome household labour constraints. Farmer adoption may increase if they suffer very substantial crop losses from CBB and other pests and diseases.

8.1.3 Soil nutrient and moisture management

Good soil nutrient and moisture management is one of the most critical climate change adaptation strategies for ensuring sustainable coffee garden productivity and maintaining tree health and resilience. Management of soil nutrients is not a high priority for farmers, mainly due to the cost and/or labour input required. Smallholder farmers allocate few resources to soil fertility and nutrient maintenance in their coffee gardens, including little or no fertilisers use. Coffee pulp and food residues are sometimes applied to coffee gardens and food gardens close to the house and to coffee trees identified as struggling. Farmers do recognise the soil health benefits of some intercrops. For example, the benefits of *Casuarina oligodon* are well understood, and *kumu mosong* (*Ficus copiosa*) is reported to improve soil nutrient status and moisture. Other species are used as indicators of soil health. Wild taro growing in the coffee garden can be an indicator of excess soil moisture.

Productivity of coffee gardens with nitrogen fixing shade trees providing optimum shade levels are relatively sustainable even with little input of inorganic or organic amendments. In these systems the net export of nutrients is minimal and moisture and nutrient levels are preserved by the mulching effect of shade tree leaf litter. However, all coffee gardens would benefit from improved soil nutrient management and for those with inadequate shade to be sustainable, restoration of appropriate shade levels with adoption of strategies that maximise nutrient cycling and improve and maintain soil fertility is recommended (Thomas et al., 2023).

Cover crops and mulching

Cover crops and mulching are recommended as effective climate change adaptation strategies. Growing cover crops is an effective strategy for controlling weeds and improving soil health, including when used as a green manure (Kiup, 2017). Generally, there is limited planned planting of cover crops in coffee gardens in PNG. Weeds and grasses are common in gardens, however, and contribute to soil protection. *Tradescantia zebrina* is found in many coffee gardens and is effective in retaining soil moisture particularly in drier areas, although it is now classified as a weed. A small number of farmers have planted pinto peanut as a leguminous cover crop. Adoption of cover crops may be low because the benefits are often not visible to farmers and the cover crops are often seen as a weed. Many farmers prefer a 'clean' coffee block, and clean blocks have been encouraged in extension. Further research is needed to understand farmer perspectives on cover crops.

Cover crops offer substantial benefits; however, they can negatively affect the coffee if they are not maintained. Many require slashing, including to keep the area around the main coffee stem clear, which is labour intensive. Farmers express preference for growing crops that they can eat or sell, and so encouraging cover crops that can be harvested for food or fodder is likely to enhance adoption. In coffee gardens close to the house, vegetable intercrops that provide the benefits of a cover crop are likely to be favoured. Non-edible cover crops may be better suited to more distant gardens because their maintenance requirements are less than that for vegetable crops. Vegetable crops at more remote coffee gardens may also be at risk of theft. Leguminous cover crops could also be incorporated within a crop rotation.

Mulches are another effective strategy to improve soil fertility and retain soil moisture. In new coffee gardens mulching is often practised to preserve soil moisture. Mulching, however, is rarely practised in mature coffee gardens. There are many readily available mulches including coffee and shade tree prunings, cover crop trimmings, weed and grass residues, banana stems, food crop residues and coffee pulp (Plate 9). However, without visible benefits mulching may be considered too much work. Farmers may also be concerned that mulching could impede access, particularly for harvesting. If farmers see the benefits of mulching in suppressing weeds and providing nutrients, and particularly in reducing labour inputs over time, they may be more willing to adopt this practice.

Plate 9. Banana stems and leaves left as mulch in a coffee garden, Makia (EHP), 2025. (Source: Tim Sharp, Curtin University)

Mulching and the management of cover crops are likely to be roles that fall to women, Women do a lot of the weeding work in coffee, so the weed suppression from mulching and cover crops may reduce women's weeding labour, and extension messaging could target this. There is, however, risk that mulching and cover crop management could add to women's already high work burden. There is also a misalignment between who is likely to do the work of mulching and tending to cover crops and who benefits from the improved health of the coffee trees, and so adoption is likely to be shaped by intra-household distribution of income. Adoption may also be limited because the effects of mulching on coffee tree health and yield are difficult for farmers to observe. Where coffee systems are already well shaded the benefits of cover cropping and mulching are reduced. These practices may, however, be a beneficial temporary measure when shade trees are being reestablished in currently under-shaded coffee gardens. Mulching and cover crops may contribute to the sustainability and climate-resilience of lower shaded intercropped systems, where labour and other inputs are already higher.

It will be important that cover crops do not impede access for harvesting, as underharvesting leads to the build-up of CBB populations. There is also risk that cover crops and mulch will conceal fallen cherries making CBB sanitation control more difficult.

Cover cropping and mulching have the potential to enhance coffee tree health and build climate resilience; however, labour availability will be a key constraint on adoption. It will also be important that these practices are implemented in ways that do not negatively affect coffee tree health and do not exacerbate pest and disease issues, which would undermine climate resilience.

Coffee pulp

Coffee cherry pulp is another readily available and under-used source of nutrients.[21] When coffee cherry is harvested, nutrients are exported from the coffee garden. Most coffee farmers make only limited use of this source of nutrients. Coffee pulp is frequently left on the ground at the pulping site. When used, the pulp is typically only used in those parts of coffee or food gardens that are near the pulping location (Kiup 2017). The use of the pulp in these locations indicates that farmers likely have some recognition of the nutritive value of the pulp. Its limited use, however, is probably due to the labour involved in returning the fresh or composted pulp to the coffee garden. If cherry is pulped in the coffee garden, the labour to return the fresh pulp to the garden is not substantial. However, if the pulping is undertaken at a distance from the coffee

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[21] Research on soil nutrient management was done as part of ASEM/2008/036 and ASEM/2016/100, and by Emma Kiup (CIC) (Kiup, 2017; Kiup et al., 2025).

garden, farmers are far less likely to return these nutrients, particularly because the pulp is wet, sticky and heavy. Most pulping occurs near the house as the pulpers are valuable assets and heavy to carry (Plate 10). Composted pulp is lighter and more manageable, however, if the compost process is not managed correctly nutrients are rapidly leached.

Plate 10. Pulping coffee near the house. Unused pulp in midground. Bena (EHP), 2017. (Source: Tim Sharp, Curtin University)

Farmers have been more receptive to using the pulp once aware of its nutritive value when expressed as a store-bought fertiliser equivalent as they then see it a cost-free method of fertilising (Curry et al. 2024). These findings have important implications for how extension messages are relayed to farmers.

Pruning residues

After pruning, residues are commonly burnt in situ or stacked at the edge of the coffee garden. The practice of burning residues in situ is appropriate if the branches are diseased but in general it would be better if the residues were left to decompose in rows in the coffee garden returning valuable nutrients to the soil. If farmers were aware of the nutritive value and benefits to soil health of the residues, they may be more likely to adopt this practice. Leaving pruning residues to decompose in place would reduce labour, however, many farmers may be reluctant to do so due to their preference for a ‘clean’ block. A risk of adopting this practice is that pruned branches and stems left in the garden may conceal fallen cherries that are then a reservoir for CBB.

Biochar (charcoal produced through pyrolysis) produced from pruned coffee and shade tree branches is another potential means to enhance soil health, including soil carbon levels. Limited availability of household labour and the difficulty in observing the benefits of that labour may constrain the uptake of this technology for many farmers. Adoption may be higher in more intensive systems.

Farmers see most soil management strategies as labour intensive and improvement in soil health is a slow process. Successful adoption would require training in these measures to make farmers aware of their value in maintaining or improving soil fertility, improving coffee tree health and improving coffee production, which would make the extra labour worthwhile. Improved pruning practices will be important for managing the effects of climate change, and opportunities for the use of pruning residues should be incorporated within training on pruning.

Irrigation

With a changing climate irrigation may be required in some of the drier coffee growing areas in PNG. Irrigation can also be used to encourage synchronous flowering (discussed above), which has labour saving and pest management benefits for smallholders. However, the cost of establishing irrigation is likely to be prohibitive for most smallholders, and this also includes low-cost drip systems. Irrigation is likely to be unnecessary in many coffee growing locations where rainfall is distributed throughout the year. Other means to maintain soil moisture including shading and surrounding vegetation, cover crops and mulching should be prioritised.

8.1.4 Other management practices

Protective covers are unsuitable for coffee smallholders in PNG due to their prohibitive cost. Coffee smallholders incomes are too low, even among the best-off farmers, to justify significant financial investment. Furthermore, shade trees provide many additional benefits beyond climate management and therefore it is more advisable that smallholders pursue this low-input approach.

8.1.5 Management of coffee berry borer

Coffee berry borer (CBB) (Plate 11) is currently a major threat to smallholder coffee production in PNG. Climate change is likely to increase the spread and the severity of CBB. The management of CBB is therefore a key climate adaptation measure, and is singled out for discussion. In addition to general good coffee garden management (pruning, weeding and shade management), CBB management requires regular harvesting every 1-2 weeks and an end of season strip pick. Both practices are targeted at disrupting the pest's life cycle and therefore keeping infestation levels low (Newton et al., 2023).

Plate 11. Coffee Berry Borer. (Source: Ian Newton)

There are several challenges to farmers adopting these approaches. As discussed, in the context of household labour constraints, labour investments in coffee decline when prices drop, and when the relative returns to labour deteriorate. Harvesting is the most resilient form of labour to declining returns, nevertheless increasing underharvesting is common when prices decline. In 2025, very high coffee prices have driven high harvesting rates, and it is likely this is currently suppressing CBB numbers. A major threat will come when coffee prices decline. Improving returns to labour during periods of low prices will be critical to CBB management (Kumie and Sharp, 2025). It will also be critical to improve the returns to women as major contributors of harvesting labour. Smallholders may also resist an end of season strip pick because immature fruit and flowers on trees are seen as future income. In addition, many farmers prefer asynchronous flowering because it spreads income and labour demands through the year. To support farmers to manage CBB will involve improving the returns to labour on coffee production, managing household labour demands, and approaches to support income outside of the peak coffee season.

8.2 Diversifying incomes

- *Livelihood diversification helps households improve food and income security.*
- *Diversifying income by growing shade/fruit trees and intercropping with vegetables or crops such as cocoa and vanilla can improve resilience and reduce household vulnerability to food and income insecurity.*
- *Benefits of income diversification are often shaped by gender roles, market access, and available resources*, which *will influence adoption*.
- *Potential risks of income diversification include increased labour demands, nutrient competition and pest and disease issues.*

8.2.1 Secondary income shade and fruit trees

Growing shade trees that are multipurpose can contribute to smallholder incomes as well as provide food, fuelwood and timber to smallholder farmers, and so contribute to food and income security in the face of climate change. The integration of limited numbers of fruit trees within coffee gardens is already common among smallholders, with farmers adapting pre-colonial agroforestry practices to coffee gardens (Strathern, 1984; Bourke, 1985). Fruit trees tend to be planted irregularly in small numbers throughout coffee gardens, although a few farmers have more substantial interplantings. Intercropped fruit trees include avocado (*Persea americana*), citrus, *marita* (*Pandanus conoideus*), bananas, tree tomato (tamarillo - *Solanum betaceum*), *laulau* (Malay apple - *Syzygium malaccense*), guava (*Psidium guajava*), *kapiak* (*Ficus dammaropsis*), *kumu mosong* (*Ficus copiosa*), *kavivi* (*Areca macrocalyx*), and, at higher altitudes, *karuka* (*Pandanus julianetti*) (Plate 12). Farmers at lower altitudes, including to around 1600 masl, have also started to experiment with cocoa (*Theobroma cacao*). Notably, there has been substantial uptake of cocoa in the Karimui area (ACIAR project HORT/2014/096).[22]

Plate 12. Coffee garden with banana, highland breadfruit, cassava, cordyline, casuarina integrated and on boundaries. Konobiufa (EHP). (Source: Tim Sharp, Curtin University)

Increased incorporation of fruit trees is likely to be of interest to farmers with good market access and are currently engaged in more commercial agriculture. Fruits receive

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[22] Betel nut (*Areca catechu*), a lowland crop for which there is a lucrative domestic market, may also be a potential future intercrop in low altitude highland areas.

good prices in the urban markets in the highlands, and the larger urban centres of Lae and Port Moresby. There is also local demand for fruit from the New Guinea Fruit Company to produce fruit wine and jams. The adoption of coffee–fruit tree systems is likely to be strongest in areas experiencing population pressure, particularly where agricultural intensification is already common and expanding. In more distant areas, fruit tree intercropping at a scale beyond supply for household consumption is only likely to be adopted if market access can be improved. In these areas, crops that have a high value to weight ratio and are less perishable would be most appropriate.

In lower altitude highland areas, farmers have started to experiment with cocoa, including the intercropping of cocoa with coffee, as well as vanilla. Intercropping of the two crops may be an adaptation transition phase whereby cocoa may over time replace coffee in areas that will no longer be suitable for coffee. Cocoa is highly susceptible to frost, so it should not be planted in areas vulnerable to frost.

There are some constraints to the greater incorporation of fruit trees into coffee systems, including:

- As with coffee trees, fruit trees need to be managed well if farmers are planting them predominantly for income. Labour availability needs to be a key consideration to guide the scale of adoption by farmers.
- Fruit trees frequently have high nutrient requirements. Consideration needs to be given as to how the nutrients exported from the farm are replaced. If nutrients are not replaced there is a risk that soil may degrade and that the trees may compete with the coffee for nutrients. Few smallholders use fertiliser on their coffee (UniQuest, 2013).
- Fruit trees may compete for available water with the coffee crop and unpruned fruit trees may also compete for light. Unmanaged fruit trees may be a source of, or refuge for, pests and diseases (both coffee and citrus, for instance, are hosts for coffee leaf rust, coffee green scale and pink disease). Greater biological diversity within coffee gardens is, however, often associated with increased presence of natural enemies of pests and diseases (Staver et al., 2001). Adopting appropriate spacing will assist to mitigate potential negative

effects, and the inclusion of fruit trees that are also hosts to the major coffee pests and diseases are best avoided in areas where CLR and pink disease pose a risk. Further research into potential secondary effects on coffee trees is required. Research is also required into the suitability of multipurpose shade trees, and the planting of fruit trees and cocoa under traditional shade trees. Fruit tree management also needs specialist skills and so farmer training will be important.[23]

- Fruit trees take several years before they produce a crop. Fruit trees are best incorporated in newly planted gardens and when gardens are being replanted or stumped. Coffee farmers are generally reluctant to replant or stump their existing coffee trees due in part to loss of income. Farmers may therefore be reluctant to adopt this strategy if it entails removal of coffee trees. Farmers may also favour planting quicker-return crops such as vegetables.
- It will be important to develop strategies to ensure women, as well as men, can benefit from fruit trees interplanted with coffee. It is common for women to plant fruit trees, including in coffee gardens, and to control the income they earn from selling the fruit in open air markets. Generally, women only plant a small number of trees and so this does not threaten male control over land. Women are likely to find it more difficult to interplant fruit trees at a larger scale, and this would require male support. Greater integration of fruit trees would be best approached through extension targeted at the family unit.

There are significant potential benefits to the greater integration of secondary income tree crops in coffee gardens, however, it will be important that extension supports the mitigation of potential negative effects.

8.2.2 Intercropping of vegetables and other non-tree crops

Intercropping of vegetables and other non-tree crops that provide food and income has the potential to be an important climate adaptation approach. In PNG, the dominant practice is for coffee to be intercropped with food crops during the establishment

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[23] This would require collaboration with other organisations with experience in fruit crops, including PNG DPI, NARI and FPDA.

phase, including bananas used for temporary shade, then gradually removed as the coffee and shade trees mature, with some residual food crops remaining in the mature garden (Bourke, 1985; Curry et al., 2017; Thomas et al., 2025). Most gardens, then, have a level of intercropping.[24] Intercropping is more common within coffee gardens close to the farming family's house with accessible garden spaces more intensively cultivated. Intercropping is less common in more distant coffee gardens due to the need for regular access to tend the food crops, and due to concerns about theft of produce. Distant gardens do, however, contain a range of other resources.

In recent years, intercropping has intensified including the intercropping of market-oriented crops. This has particularly occurred in accessible sites where population pressure and market opportunities are driving intensification (Curry et al. 2017). Intercrops include cabbage, carrot, pumpkin, *Xanthosoma* taro, bananas, sugarcane, corn, sweet potato, sugar fruit (*Passiflora ligularis*) and beans (Plate 13).

Farmers also selectively intercrop to manage soil health when coffee trees are observed to be performing poorly. Xanthosoma taro and banana, for example, are used by farmers to open the soil structure for the coffee roots and to maintain soil moisture (Plate 14). Farmers in the Korofeigu area (EHP) also reported that cooking bananas intercropped within heavily shaded coffee were an important source of food during seasonal dry periods. Farmers also routinely incorporate a range of medicinal plants, flowers, and plants used for fibre and cultural purposes. Suitable vegetable crops also act as a cover crop supressing weed growth and can improve soil health if they are nitrogen fixing. Intercrop residues also add nutrients to the soil.

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[24] Tilden et al. (2024) note that surveys of two sites near urban markets (Asaro and Bena), 'three-quarters of all coffee gardens were intercropped, and of these gardens, 60% had up to 20% of the coffee garden area intercropped, and 27% had 20–40% of the area intercropped' (Tilden et al. 2024:390). In a recent survey of 24 coffee gardens in the Konobiufa area (Eastern Highlands), JAF M. Phil student Vincianna Andrew, recorded over 40 different non-tree fruit, vegetable and medicinal species being intercropped within coffee gardens.

Plate 13. Choko growing under unshaded coffee, Asaro (EHP), 2022. (Source: Tim Sharp, Curtin University)

Plate 14. Xanthosoma taro and bananas intercropped in a coffee garden shaded by Albizia sp., Korofeigu area (EHP), 2025 (Source: Tim Sharp, Curtin University)

Coffee farmers, responding to the changing climate, have also recently started to experiment with vanilla (Plate 15), including within coffee-cocoa systems. Vanilla is a potentially high value crop that could be suited to remote areas due to its high value to weight/volume ratio, however it does require significant labour and specialist knowledge (McGregor, 2005). The potential for vanilla to be incorporated within lower elevation coffee agroforestry systems justifies further research.

Intercropping is likely to be more important for farmers in areas with good market access and where there is already intensification of land use due to population pressure and the growth of fresh food marketing. More remote farmers may also benefit, however, marketable intercrops would require high value to weight/volume ratios and lower perishability (e.g. vanilla, chilli and ginger).

Plate 15. Vanilla growing on cordyline within a shaded coffee system, Korofeigu area (EHP), 2025. (Source: Tim Sharp, Curtin University)

Intercropping of annuals and short-lived perennials is likely to benefit women who have primary responsibility for household food supply and for the marketing of fresh food. The greater incorporation of intercrops within coffee gardens provides a potentially important pathway to increase the benefits of coffee systems for women, and improve their access to land for food production in land-short areas. It also affords women access to land nearby the residence for food gardening. More research is needed to understand the gendered effects of changes within coffee agroforestry systems.

A key benefit of intercropping is its potential to indirectly encourage improved coffee garden management. Food crops are regularly weeded, and this can benefit the coffee. Coffee trees may also benefit from pruning directed at improving the light available to the intercrop, although pruning is generally done by men. Increased opportunities to observe pests and diseases within the coffee is also beneficial. Women working in coffee gardens more frequently may also increase regular small-scale harvesting of coffee cherry to earn money to meet immediate household needs. This may contribute to reduced CBB incidence as regular harvesting, to reduce unharvested cherry acting as a reservoir for CBB, is a key management strategy for controlling CBB (Newton et al., 2023). The additional labour invested in the coffee garden is also incidental, and so suitable in contexts where labour availability is constrained.

The incorporation of effective intercropping systems is also likely to encourage farmers to keep coffee in the ground as it enhances the overall value of the coffee system, and so intercropping should not be seen as a stepping stone out of coffee. In areas with good market access and pressure on land, a growing number of smallholders have uprooted their coffee to expand fresh food production for domestic markets. Intercropping, if done well, can provide a means to both maintain coffee as well as expand food production.

Some risks associated with intercropping coffee are the potential competition for nutrients and water between the coffee and the intercrops, and intercropping leading to an unsustainable export of nutrients from the coffee production system. It is common practice for smallholders to fertilise commercial crops such as cabbages, broccoli, and carrot. Coffee can benefit from this fertiliser application, and this may prevent or slow overbearing dieback within under-shaded systems (Curry et al., 2024). Fertiliser is not, however, generally applied to indigenous crops or non-marketed crops. There is risk that if additional nutrients are not applied (whether in the form of fertiliser, composts, N-fixing trees or legumes), intercropping will increase the net export of nutrients from the coffee garden, and that there will be competition between coffee and the intercrops for available nutrients, with the potential to negatively affect both the coffee and the intercrops.

Another risk is that pesticides commonly used on commercial crops may undermine the potential for coffee certification. They also pose a risk to human health, particularly given the inadequate use of safety equipment, emphasising a general need for training on integrated pest management approaches (Zapata Diomedi et al., 2016). Maintaining diverse systems may, however, increase predation of problematic pests and diseases and so reduce the need for pesticide use.

Intercropping may also affect access to the coffee trees, although it may also improve access due to increased weeding. Intercrops with a spreading and climbing habit such as some beans, may negatively affect the coffee if not managed.

The adoption of intercropping will likely be shaped substantially by the level of benefit that accrues to women and the family more generally. Women are the main producers and marketers of fresh food, although men's involvement in production and marketing is increasing (Sharp et al., 2022). In those areas where there is population pressure on land availability, women will likely take up intercropping, as they already are, to gain access to land, particularly land near their residence. Land near the residence is also valued in areas where land supply in the broader area is not a significant issue. However, in those areas without pressure on land, there will need to be observable benefits for women.

The total value of output from an intercropped coffee system can exceed the value of single crop systems per area of land, and at the household level. However, it is important that the system also offers good returns to labour for women. Women are likely to benefit from the income earned from the sale of intercropped food crops; however, men have typically controlled the income from coffee. That is, the benefits to the coffee tree from intercropping will likely be benefits that accrue largely to men. There is a risk that women's weeding labour, and their inputs of nutrients (whether purchased fertiliser or the labour invested in mulching and composting), would not directly benefit them if there are no changes to the gender distribution of coffee income within the household. As with other adaptation strategies, there will also be a need to support strategies, which cultivate more gender equitable coffee systems. While it is important to raise these cautions, that women are increasingly intercropping is a strong indication that there are strong benefits, at least to some women. More research is needed to understand the gendered distribution of benefits.

Further research is required to support the sustainability of these systems and avoid problematic competition for nutrients/light/water or depletion of soil.[25] The systems

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[25] When evaluating intercropping it will be important to consider: coffee tree spacing – in a new coffee garden a wider spacing could be recommended if permanent intercropping is intended (this has benefits

need to be sustainable from an agricultural perspective, but they also need to align with the social system.

8.2.3 Other non-coffee economic activities

Diversifying coffee farmer livelihoods is an important strategy to support climate resilience and to mitigate other shocks including market fluctuations, and pests and disease outbreaks. The sections above describe strategies for farmers to diversify their production and income sources within their coffee gardens. Farmers should also be supported to diversify their livelihoods more broadly.

Maintaining diverse livelihoods enables coffee farming families to have more frequent access to income and spread expenditure over the year (Inu 2015). As discussed above, most coffee farming households already have multiple sources of income in addition to coffee, particularly in accessible sites. Coffee farming families already recognise the benefits of diverse livelihoods, however, there are substantial constraints to income diversification and to the development of small enterprises in rural PNG (Koczberski et al., 2021b; Sharp et al., 2025). For some activities upfront costs may be a substantial barrier to farmer adoption, and there may also be skill or gender barriers in adopting new activities. There is value in supporting skill development in financial literacy and the management of small and micro-enterprises, as well as providing access to saving and credit facilities (Koczberski et al., 2021b).

CIC has in recent years engaged in projects to strengthen livelihoods of coffee farming families beyond a coffee-production focus. A recent ACIAR-funded pilot of Village Savings and Loans Associations within a coffee farming community in the Eastern Highlands has demonstrated their capacity to build savings, support small-scale enterprise and support skill development and confidence (Koczberski et al., 2021b; Sharp et al., 2025). It enabled members to save income, including from coffee. The

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in pest and disease management); types and varieties of intercrops for different situations and locations; the export of nutrients from the garden and how these should be replaced – fertiliser applications may be required; the benefits to soil fertility of growing legumes as intercrops; and how coffee garden maintenance can be improved when growing intercrops; Extension training should emphasise the value of keeping the coffee trees in the ground, including ongoing income and greater tolerance to extreme environmental conditions, especially drought. In areas of high population pressure, intercropping may be an alternative system to shaded coffee if moisture and nutrients are adequate.

savings groups also led to increased investment in coffee. CIC has, subsequently, incorporated this savings group model into their work with coffee grower groups.

Beekeeping has also expanded in the highlands in recent years, including with support from ACIAR funded projects involving CIC (LS/2014/042, FST/2014/067). Honeybees contribute to the pollination of coffee and so potentially improving yields, and bee-keepers earn income through the sale of honey. Short-rotation coppice agroforestry may also provide an alternative income source that has potentially good returns to labour (Nuberg et al., 2017; Bourke, 2022), and may deliver other benefits to coffee systems.

Initiatives that support livelihood diversification are likely to particularly benefit women, especially when new income opportunities are not land-based, or where they either have minimal dependence on land or require short term access. These activities will also support other community members, including migrants, who do not have strong claims to land.

There is a wide range of potential additional income sources for coffee farming families. The critical point is these alternative activities should be seen to complement rather than compete with coffee. Driving new farm and non-farm income initiatives will require collaboration with other organisations with relevant expertise.

8.3 Planting climate-resilient coffee varieties

- *Development and adoption of climate-resilient coffee varieties is a key long term adaptation approach.*
- *New climate-resilient varieties need to be evaluated for suitability for smallholder management and labour availability*

Growing coffee varieties that are more resilient to the effects of a changing climate will be a key climate adaptation strategy for smallholder coffee farmers in PNG. In the short-term, farmers can use their existing varieties that are known to be hardy, deep-rooted, tolerant of warmer temperatures and water stress, and more tolerant to pests and diseases, notably CLR, which can seriously affect lower altitude gardens. In the longer-term, there may be opportunities to adopt new varieties, and there are some early efforts underway.

Varieties and species selected need to be suited to smallholder farming and livelihood systems in PNG, in particular to a low-input approach. Coffee smallholders in PNG generally prefer tall varieties over dwarf varieties. The taller varieties such as Typica, Arusha, Bourbon, and to an extent Mundo Novo, are hardier and more tolerant than the newer shorter varieties of low levels of management, albeit susceptible to CLR. Typica is the hardiest of the tall varieties and is recommended in drier areas due to its drought tolerance. Smallholders also do not like the higher planting densities of the dwarf varieties due to difficulties in accessing the garden for harvesting and maintenance (Curry et al., 2023c). Planting material is also more readily available as they are far more widely planted throughout the highlands (UniQuest, 2013:36-7). There are some trade-offs that require consideration. For example, the semi-dwarf variety Catimor is tolerant of CLR, and recommended in areas where CLR is a serious problem, although, it is less hardy and requires higher labour input than existing tall varieties (Curry et al., 2023c).

With the threat of climate change on coffee production, plant breeders have sought to develop coffee varieties with a range of climate resilient traits. The trialling of new varieties is a long process, and trialling has generally not occurred in smallholder settings. Currently, CIC is participating in a World Coffee Research multi-locational varieties trial, with PNG trial sites at three locations at different altitudes. The coffee trees in the trial are young, and only minimal yield data has been collected to date. CIC has also been trialling plantings of Maracaturra, a hybrid of Maragogipe and Caturra, which shows promise due to its hardiness and large bean size (Plate 16).[26]

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[26] CIC is also currently trialling marcotting which could be beneficial to farmers for cloning high performing coffee trees which would be a preferred option over propagation by seed. Evidence from these trials so far has shown that trees propagated by marcotting have a reduced time to initial harvest compared to seed propagated trees but the impact on root development and therefore climate resilience is still unknown.

Plate 16. CIC Maracaturra trial site, Tairora area (EHP), 2024. (Source: Tim Sharp, Curtin University)

International plant breeding has included the development of F1 hybrids. F1 hybrids generally produce greater yields than traditional coffee varieties, however, they also require higher labour and fertiliser inputs (Kahsay et al., 2023). There are also risks that smallholders in PNG will not consistently maintain the recommended levels of labour and fertiliser inputs. Therefore, the suitability and productivity of these varieties under smallholder conditions needs to be considered.

Adoption of hybrids, which require clonal propagation, is affected by availability and expense of planting material. The Starmaya variety, that is currently being trialled by ECOM/Monpi and CIC in PNG, shows great promise as it is the only F1 hybrid that can be seed propagated.[27] If adopted by smallholders there is a risk, some farmers may try to propagate seed from these trees with the resultant second generation plants expressing a diverse variety of traits (both desirable and undesirable) from the initial

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[27] Starmaya seed is produced in seed gardens of the two parents (the mother plant being a sterile male) with external pollinators excluded. This produces seed that can be distributed (Georget, 2019).

parent plants. Studies have reported that most smallholders obtain new planting material from volunteer seedlings from within their own coffee gardens (UniQuest, 2013:36; Curry et al., 2017:31). Farmers would also not be able to identify the quality of the second generation of planting material for several years. The adoption of hybrids in the smallholder setting will require substantial farmer training, and even then, would retain long-term risks as seed may move beyond those areas where training has not occurred. The development of a reliable seed supply could reduce this risk.

Nevertheless, the adoption of hybrids may, be beneficial to farmers located in areas most vulnerable to the effects of climate change. The breeding and trialling of new varieties takes a long time. PNG smallholders are often very interested in experimenting with new crops and varieties, and it is likely that they would be interested in new varieties. New varieties should be evaluated under low-input smallholder conditions. Cultivating coffee within agroforestry systems is the most suitable for the PNG smallholder context, so identifying those varieties that perform well under shade is important. The environmental diversity in PNG's coffee growing regions, and the diverse livelihood strategies of farmers, means that a selection of different varieties exhibiting different traits will be needed.

Robusta coffee (*Coffea canephora*), which is grown at lower altitudes in PNG, is limited in its potential as an alternative to arabica. Robusta makes up only a very small proportion of coffee production in PNG, most of which is grown in East Sepik Province. Production levels have, however, been low since the early 2000s with farmers shifting to cocoa and vanilla (Allen et al., 2009:307). In 2025, a CIC program was focused on rehabilitating and expanding robusta coffee in several lowland provinces. Robusta is considered lower quality and therefore lower value than arabica – although robusta prices have been high recently, and there is an emerging market for specialty robusta. PNG is not well placed to compete with the main robusta producing counties such as Vietnam and Brazil on production costs, and so the returns to labour for robusta production are particularly low (Bourke, 2022). The low returns to labour will be a major disincentive to adoption, and a shift to robusta is not a recommended strategy unless these returns to labour can be significantly improved. Robusta may be an option for some farmers at lower elevations for whom there are no alternatives, however, it is unlikely that it would be widely adopted. Robusta is also sensitive to low temperatures and is affected by CBB, which reduces its suitability as an alternative crop. High altitude areas in PNG mean that PNG, as a whole, is likely better placed in the face of climate change than many other arabica producing countries, and so a focus on tapping into higher value arabica markets is likely a better policy direction.

The adoption of more climate resilient coffee varieties may be slow due to the reluctance among smallholders to replant their coffee gardens. Replanting is costly and many smallholders may not have the financial resources to fund a major replant without external support or financial incentive. Farmers will also require adequate extension support. While the development and adoption of climate-resilient coffee varieties will be a key adaptation approach, particularly in the long-term, this needs to occur in combination with other adaptation approaches. It will also be critical that new varieties are evaluated under smallholder conditions.

8.4 Changing location of coffee gardens

- *Moving coffee gardening from vulnerable low elevation areas to higher elevations and local microclimates that will be more suited to coffee.*
- *Land availability will constrain this adaptation strategy for many smallholders.*
- *Expansion of coffee gardens into new areas must consider the potential negative effects on existing land uses (including forested areas and gardens), food security, livelihoods, labour and market access.*

Changing the location of coffee gardens, including to higher altitudes and to locations with favourable microclimates, could be an effective and suitable climate adaptation option for some coffee smallholders. The ability of smallholders to adopt this approach will depend on land availability, and this differs considerably between communities and households within the same community. Smallholders are generally restricted to planting coffee on land held by the clan/subclan of the male smallholder. Individuals typically have gardens, including coffee gardens, in a clan's land area, and often within different environments, including altitudes, microclimates and land types. Access to these different environments will differ between and within landholding groups (Brookfield and Brown, 1963). Thus, some smallholders may possess land areas that allow for expansion, whereas others may live within territories in which the potential for agricultural expansion is constrained. Some members of a community may have limited access to land because they are not residing and farming on their own clan land.[28] Available land may also not be suitable for coffee. The location and area of land planted under coffee has not changed considerably over time due to the constraints on the expansion to the area under coffee cultivation. With growing population pressure on land in parts of the highlands, land availability will be a significant constraint to this adaptation approach.

It is possible that some smallholder families may be able to increase their management and harvest effort of their existing higher altitude gardens and hence improve their productivity. Smallholders are already reporting doing this in response to improved flowering at higher elevations. At present, a substantial proportion of coffee is planted on land in climate zones that historically were cooler than the optimum growing conditions for coffee, however, increased temperatures under climate change may improve suitability in these areas (CSIRO and SPREP, 2022:10).

Many smallholder families in PNG have multiple coffee blocks (Curry et al., 2017:30; Eves and Titus, 2020:37), sometimes at different altitudinal ranges. Smallholders may therefore be able to invest more labour in gardens at higher altitudes to offset losses at lower altitudes. As coffee production becomes more viable at higher altitude it is also likely that new farmers will take up coffee production, just as existing farmers at lower altitudes abandon coffee. Farmers also recognise that their higher altitude gardens, and gardens with cooler microclimates, are less affected by CBB and CLR. Many coffee farmers in the lower altitudes are seeing substantial losses to CBB, and so they are likely to recognise the potential benefit of increasing coffee in higher altitudes and in local areas with suitable microclimates.

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[28] People not belonging to the local landowning group may through agreements with landowner’s access land to grow food, and may rent land for short periods for a commercial vegetable crop. Such arrangements are less likely for long term crops such as coffee.

There are a range of risks associated with expanding coffee into higher elevation areas and other areas with suitable microclimates. The most significant of these risks is the potential displacement of existing land uses. Encouraging planting of coffee in new areas may lead to deforestation within higher altitude areas and local microclimates (Plate 17). Furthermore, if food gardens (including those in fallow) are displaced by coffee, their relocation may indirectly lead to deforestation. The loss of forested areas is likely to threaten beneficial ecosystem services and access to forest resources, including hunting grounds. Deforestation would also undermine people's access to higher value markets for sustainably certified coffee and to the European Union market, which will only accept coffee from suppliers who can guarantee it has not contributed to deforestation.

Plate 17. Expanding coffee to higher elevations may cause deforestation and displace current food gardening. Okapa district (EHP), 2024. (Source: Tim Sharp, Curtin University)

Higher altitude coffee plantings may also undermine household food security. The expansion of coffee may compete for land for food production, displacing existing food gardens and fallowed gardens. Farming families also need to adapt their broader farming systems to climate change, including in relation to food crops, not only their coffee systems. Thus, it is important that their adaptation of coffee systems does not negatively affect their capacity to adapt their food and livelihood systems more broadly.

Expanding coffee into new areas will likely entail a shift to less accessible areas and limited road access to markets will be a major constraint and disincentive. More distant coffee gardens frequently receive less management input, and lower harvesting intensity than gardens that are closer to the smallholder's house. There is a risk that, if established, more distant gardens will not receive adequate management. More distant gardens may also add to farmer workloads due to longer travel times, and for this reason shifts may be resisted. Smallholders are often concerned about theft of cherry in distant gardens, and this may affect willingness to invest labour in distant gardens. Smallholders are unlikely to move their residence further away from services to be closer to their coffee gardens.

As smallholders expand plantings in new areas, there may be reluctance to remove existing plantings. Labour constraints mean that many households already struggle to adequately manage their coffee, and so expanding coffee holdings may lead to declining management of existing coffee, which is particularly problematic in the CBB context. Where new coffee is planted on existing fallowed land, this will also lead to an intensification of land use, and potential for land degradation resulting from the shortening of fallow periods for food crops.

Planting coffee at higher elevations and in better local microclimates will be an effective adaptation strategy for those farmers with land available, however, many smallholders will not have suitable land available to them. For those smallholders for whom it is an option, it will be important that this shift is well considered for its potential effects on other land uses and livelihoods, labour and market access. These considerations should be incorporated into extension messaging. For farmers without the ability to move, the focus of extension should be on adaptation in place.

8.5 Transitioning away from coffee

For coffee farmers most affected by climate change and unable to adapt their coffee management practices, transitioning to other income sources may be the best option. There are significant livelihood resilience benefits to households retaining coffee production as part of a diverse range of livelihood activities, and so adaptation measures that contribute to supporting coffee production should be prioritised. However, for some farming families their social, economic and geographic context may mean a shift away from coffee is a sensible livelihood strategy.

In lower altitude areas where the climate is likely to become less suited to arabica, and where the effects of pests and diseases, notably CBB and CLR, are likely to be greatest, coffee production is anticipated to be increasingly unviable. The adoption of other adaptation measures may extend the viability of coffee in these locations, however, in areas most affected by changes in the climate, successful adaptation is likely to require substantial shifts to existing production practices, which may be too onerous for many farmers (Curry et al., 2015). Eventually, these farmers may find it better to transition out of coffee.

The appropriateness of a transition out of coffee will also hinge on the other sources of income available and the relative returns to labour. In accessible areas, as coffee becomes increasingly marginal, climate change is likely to further drive increased participation in fresh food production for domestic markets, and ultimately a transition out of coffee. Furthermore, if the costs of implementing adaptation measures substantially reduce the returns to labour relative to alternative income sources, then it may be better to support farmers to establish alternative income sources. Income diversification strategies (Section 8.2), by improving the benefits of the broader coffee farming system, can help farmers to retain coffee as part of those systems. In the longer term, where other adaptation approaches become unfeasible or too onerous, and so coffee production is no longer viable, the availability of other sources of income can support a less disruptive transition away from coffee.

The most vulnerable areas to the effects of climate change, will be remote lower altitude coffee producing areas, which are currently, or will become, marginal for coffee production. More remote areas have particularly poor access to extension services and information, and so are likely to have poorer adoption of climate adaptation measures. Households in remote areas are also generally heavily dependent on coffee production for income, and have few alternative income sources, which means there are no obvious pathways to transition out of coffee, although cocoa and vanilla are emerging options (Plate 18). If these areas are not supported to adapt and ultimately transition, people in these areas are likely to experience declining livelihood security. However, it is important to recognise the majority of existing coffee growing areas in PNG are predicted to remain suitable for coffee production in 2050, and so for most farmers climate adaptation support should focus on enhancing the climate resilience of coffee farming systems.

Plate 18. Recently planted cocoa intercropped within shaded coffee, Makia (EHP), 2025. (Source: Tim Sharp, Curtin University)

9. Conclusions and recommendations

Climate change is already reshaping the environmental conditions under which coffee is grown in PNG, particularly in the highland regions. The vulnerability of PNG's coffee systems is compounded by socio-economic challenges, including limited access to extension services, low-input farming practices, and constrained market access. Despite these challenges, the resilience and adaptability of PNG's smallholder farmers create an opportunity for targeted climate adaptation strategies.

The high altitude of PNG's arabica coffee growing region means that the climatic effects on PNG are likely to be less severe than those in many other coffee growing countries. Many of PNG's coffee plantings are likely to continue to have climates suited to coffee, and so there are potential opportunities for PNG. However, because low-input farming systems are common and, and adoption of farming technologies and practices is low, climate effects on farmers may be severe. The decline of government agricultural extension services in the country will also limit adaptive capacity.

The anticipated increase in mean annual temperatures by 1–2 °C by the 2050s, particularly in highland regions, will mean higher altitudes may become more suitable for coffee growing. Lower-altitude regions are likely to experience declining productivity. A targeted approach to climate adaptation practices in these regions will be important. Rainfall projections remain uncertain, but increased variability and intensity are expected, further complicating crop management and increasing the risk of droughts and soil erosion.

To create a more resilient PNG coffee industry and to support the livelihoods of coffee farming, a range of climate adaptation strategies that could be implemented in smallholder coffee systems were explored. Based on this evaluation the following recommendations are made:

1. Adopt a whole of system approach to climate adaptation

Successful climate adaptation of coffee systems will require a whole systems approach, which includes recognising the livelihood diversity of coffee farming families. Climate adaptation must work with coffee as part of a broader agricultural system, not as a single crop. Climate adaptation must also recognise that coffee gardens are species diverse. Climate adaptation strategies are more likely to be adopted if they align with the livelihood priorities of smallholder coffee farming families. It is important to recognise that climate change is not just affecting coffee systems, but livelihood and farming systems more broadly, and that in addition to climate change, other pressures on livelihoods including population growth, a changing economic environment, and social changes, are also driving changes in livelihood and farming systems.

2. Diverse adaptation approaches are needed

Coffee in PNG is farmed in a diverse range of environments and different altitudes, and different approaches are relevant to each. Smallholder coffee farming families are also diverse and will require diverse climate adaptation approaches. Further work is needed to tailor adaptation approaches and extension support to different contexts and to different types of farmers with differing capacities and needs. Successful climate adaptation with require a combination of approaches, and these will change over time as the climate changes. While farmers should be supported to continue to produce coffee as much as possible, for those farmers most vulnerable to the changing climate it will be important that they are supported to transition away from coffee.

3. Prioritise low-input approaches

Climate adaptation approaches need to align with the low-input production strategies employed by most smallholder coffee farmers in PNG. Climate adaptation strategies that require high or even moderate labour or capital inputs are unlikely to be adopted. Household labour constraints will be a main limiting factor to adoption of different strategies, with technologies and approaches that reduce labour inputs more likely to support adoption. Those adaptation options that assist women and young adults to benefit from coffee production may help to overcome household labour constraints. Further research is needed to support approaches that overcome household labour constraints due to the main influence this will have on adoption.

4. Support more equitable coffee farming systems

Engaging women and young people in coffee farming, and enhancing the benefits they derive from coffee systems, will be critical to the adoption of many climate adaptation practices. Approaches that improve returns to labour will help support adoption. This includes strategies to improve prices smallholders receive and labour efficiency. Supporting connections between smallholder farmer groups and coffee buyers and exporters, including through certification schemes, will support improved quality and higher prices.

5. Strengthen extension services and farmer training

A significant reinvestment in coffee extension services is needed to enable farmers to implement climate-smart practices. Using resources such as *Smallholder coffee production in Papua New Guinea* training guide (ACIAR Monograph No. 220), can provide information to support extension officer knowledge and extension activities. A shortage of government extension officers means it will be important to work through the private and NGO sectors, and to explore strategies to support farmer-to-farmer knowledge sharing that could expand the reach of CIC's extension, which delivers extension through farmer groups and cooperatives. Coffee extension needs to be supported by research on adaptation, and on the adoption of adaptation practices. Research is also needed to investigate effective extension communication and learning approaches that are interactive and co-create knowledge on climate adaptation practices with coffee farming communities.

6. Improve current coffee systems

Improving the current smallholder coffee systems in PNG such as improving shade trees that can buffer temperature extremes, improve soil health, and reduce pest pressure will create coffee systems that can adapt to the short-term shocks of climate change, and build resilience to long term effects. These changes should also build on local innovations such as intercropping practices and the adoption of new crops (such as cocoa and vanilla) that are likely to be well suited to the climate. Farmers need to be supported to make these changes in ways that are sustainable and deliver the most benefit to farming families. This will require both agronomic and social science expertise.

7. Support smallholder management of coffee berry borer

CBB is a serious existing threat to smallholder coffee in PNG, and CBB infestation is likely to spread and intensify under a changing climate. CBB levels can be effectively managed through regular harvesting and end of season strip picks to break the insect's life cycle, and through routine garden maintenance and sanitation practices (Newton et al. 2023). Household labour availability is the greatest constraint to CBB management. Strategies that overcome labour and improve returns to labour will support CBB management. The industry also needs strategies to support farmers to maintain CBB management when prices are low.

In conclusion, climate adaptation in PNG's coffee systems must be relevant, equitable and context sensitive. Successful climate adaptation will involve exploring the potential of existing and new agricultural practices and working to align these with PNG's agricultural and livelihood systems. Doing so will contribute to both sustainable livelihoods and a more resilient PNG coffee sector.

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ACIAR Smallholder coffee production training package

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Extension Officer Training Program

Title	Module reference
Smallholder coffee production in Papua New Guinea Training Package	ACIAR Smallholder Coffee Production in Papua New Guinea Training Package
Extension Principles	
Introduction to the Coffee Extension Officer and Farmer Training Guides	ACIAR Extension Officer Training Guide Unit 1 Module 1
The extension officer - roles and effectiveness	ACIAR Extension Officer Training Guide Unit 1 Module 2
Knowing Your Farmers	
Getting to know our coffee smallholders	ACIAR Extension Officer Training Guide Unit 2 Module 1
What factors affect smallholder coffee production?	ACIAR Extension Officer Training Guide Unit 2 Module 2
Strongim grup: course facilitator guide	CARE Organisational Strengthening Training

Farmer Training Program

Title	Module reference
Becoming a Coffee Farmer	
Knowing your coffee tree	ACIAR Farmer Training Guide Unit 1 Module 1
Coffee nursery development	ACIAR Farmer Training Guide Unit 1 Module 2
Establishing a new coffee garden	ACIAR Farmer Training Guide Unit 1 Module 3
Managing Your Coffee Garden	
Weed control	ACIAR Farmer Training Guide Unit 2 Module 1
Maintenance pruning and rehabilitation	ACIAR Farmer Training Guide Unit 2 Module 2

Shade management	ACIAR Farmer Training Guide Unit 2 Module 3
Drainage	ACIAR Farmer Training Guide Unit 2 Module 4
Pest and disease management	ACIAR Farmer Training Guide Unit 2 Module 5
Coffee berry borer management	ACIAR Farmer Training Guide Unit 2 Module 6
Soil fertility and nutrient maintenance	ACIAR Farmer Training Guide Unit 2 Module 7
Intercropping in your coffee garden	ACIAR Farmer Training Guide Unit 2 Module 8
Harvesting and Processing Coffee	
Coffee harvesting and processing	ACIAR Farmer Training Guide Unit 3 Module 1
Coffee grading systems and pricing	ACIAR Farmer Training Guide Unit 3 Module 2
Establishing a mini wet factory	ACIAR Farmer Training Guide Unit 3 Module 3
Coffee Marketing	
Understanding the domestic coffee market	ACIAR Farmer Training Guide Unit 4 Module 1
Kamapim ol praioriti	CARE Organisational Strengthening Training
Kamapim ol eksen plen	CARE Organisational Strengthening Training
Setim gutpela kastom bilong ronim grup	CARE Organisational Strengthening Training
Wok bilong meneja na memba na lida	CARE Organisational Strengthening Training
Coffee certification	ACIAR Farmer Training Guide Unit 4 Module 2
Fairtrade certification	ACIAR Farmer Training Guide Unit 4 Module 3
Family Money Management	CARE Family Money Management Training

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