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Fiji taro climate-smart demonstration farms

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This report has been produced by the Australia Pacific Climate Partnership (APCP) for a collaborative project with the Fiji Ministry of Agriculture, with contributions from Johanna Johnson, Hannah Barrowman and Poasa Nauluvula.

It provides a summary of the taro demonstration farms project results, recommendations relevant to taro farming in Fiji in the context of climate change, as well as next steps for climate-smart farming practices. It is supported by the climate science in '*Potential impacts of projected climate change on root crop production in Fiji'* produced by the CSIRO NextGen project.

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Executive Summary

Climate change and disasters regularly disrupt agricultural productivity, supply chains and critical transport infrastructure, with subsequent long and costly recovery lags. While understanding of these climate impacts is improving, there are limited practical examples of how agriculture can adapt. This study builds on a collaboration between the Australia Pacific Climate Partnership (APCP) and the Pacific Horticulture and Agriculture Market Access (PHAMA) Plus Program (Phase 1) conducted in 2020. Phase 1 was undertaken in the four main root crop growing regions of Fiji and identified potential climate change impacts and adaptation interventions to minimise these impacts on root crops. Phase 2 partnered with the Ministry of Agriculture and farmers to trial some of the adaptation interventions to demonstrate potential climate-smart practices and test their effectiveness at minimising climate impacts. Taro was selected as the demonstration crop since it is a staple crop grown in all 14 Provinces of Fiji for food and income.

The demonstration farms were established in four taro growing regions of Fiji – Taveuni, Namosi, Savusavu, and Naitasiri. At each demonstration farm, the farming practices tested were standout solutions from Phase 1 that offered real promise at enhancing climate resilience. They included organic farming (with agro-forestry elements) and traditional farming practices, complemented by the farmers usual practice that acted as the control plot. Conventional farming practices recommended by the Ministry of Agriculture were also tested on one plot at each demonstration farm, and included the application of chemical fertilisers and pesticides. Noting that the demonstration only collected data for one season so cannot be correlated to long-term climate change, the farms showcased how existing farms can implement a range of agricultural practices with the potential to minimise climate impacts without significant changes to operations or labour costs. Farmers also had the opportunity to plant the taro leaf blight resistant variety and test its performance against their usual variety.

Results showed that:

- Climate conditions drive all stages of taro farming, from planting time to crop growth, harvest timing, size and quality at harvest, and sales price.
- Early or late planting may be preferable as the rain season shifts, to avoid planting in heavy rains and/or loss of seedlings.
- Taro crops grow faster and can be harvested in 6-8 months under warmer temperatures.
- Soil moisture was correlated with taro yield and yield was greatest under normal to slightly dryer soil moisture conditions.
- Traditional practices that were a combination of agro-forestry and organic farming are likely to perform best under future climate change conditions.
- Organic farming plots were impacted by pests and disease and may require more flexible application given projected increases in temperature and extreme rainfall that promote pests and disease.
- Conventional farming practices with chemical inputs performed only moderately well, and while they may be effective today, they will become less effective over time as changing climate conditions continue.
- Pests, diseases and avoiding flood-prone areas need to be considered from the outset. However, any maladaptation, such as expanding farming into virgin forest areas, to avoid flooding or other climate impacts, should be avoided.
- There were no additional costs in time or people to set-up the different practices.

- Taro farm-gate prices influenced the value of crops, which highlights the importance of negotiating fair and equitable prices and access to export markets for all regions.

Ultimately, incorporating traditional knowledge that has been acquired over generations by taro farmers is important for selecting and applying suitable farming practices that will minimise the impacts of climate change. And climate-smart practices are generally based on traditional practices that can minimise the impacts of increasing temperatures, more extreme rainfall events, flooding, and pests and disease. With conventional practices that use chemical inputs likely to become less effective over time as changing climate conditions continue.

Introduction

Taro production in Fiji

In Fiji, all 14 Provinces produce taro (also known as dalo), however one island (Taveuni) supplies up to 80% in volume of the preferred export variety, the Tausala ni Samoa. Taro crops are almost entirely produced by smallholder farmers, and are important staple foods and export commodities, therefore, they are a high priority in terms of food security and income generation. Taro is also an important crop in Fiji for disaster recovery, often used during times of emergency, such as after a cyclone, or in times of food shortage.

The vulnerability of root crops throughout the Pacific has been well-documented (Taylor et al. 2016), as well as key risks to specific crops, such as taro (Crimp et al. 2017). In many Pacific nations including Fiji, successive severe tropical cyclones, floods and drought have become major disruptors to agricultural production and as a consequence, rural and export businesses. For example, the amount of taro planted and produced in Fiji declined significantly between 2013 and 2016, during a period where Fiji was affected by two severe tropical cyclones and a prolonged drought. The area of taro planted in 2016 was only 25% of that planted in 2013, and production fell by 50% from 93,000 tonnes in 2013 to 43,480 tonnes in 2016 (AECOM & Kalang 2018).

The impacts of continued and accelerating climate variability and change are recognised as real threats to the livelihoods, food security and nutrition of the people of the Pacific islands. Field trials in Fiji have shown that taro yield is little affected by temperature increases up to 2°C but there is a noticeable decline of 10-12% at 3°C. Future temperature increases will accelerate crop maturity by about two weeks for every 1°C increase in temperature (Crimp et al. 2017). Therefore, the standard 9–10 month crop cycle in Fiji could reduce as temperatures increase.

There are also positive responses with yield increasing under higher atmospheric carbon dioxide (CO_2) concentration ('CO_2 fertilisation' response typical in many crops). The lowest taro yield was associated with declines in rainfall and higher temperature combined (-15% and +3°C), coupled with the lowest CO_2 concentration (420 ppm). Conversely, the highest taro yield was associated with high CO_2 concentration (500 ppm), modest declines in rainfall (-5%) and increases in temperature (1°C) (Crimp et al. 2017). Growth response is therefore complex, and understanding climate risks and identifying appropriate adaptations to address combined impacts is key to future resilience of taro farming.

In Fiji, there has been progress by the Ministry of Agriculture (MoA) in identifying and developing crop varieties that can cope under extreme conditions like prolonged droughts, higher salinity, flooded soils and extreme temperatures. Traditional crop varieties and wild relatives have genes resistant to pests and diseases and characteristics to cope with extreme climatic conditions, more than imported varieties. Some taro cultivars are known to have extreme flood tolerance, very few varieties are drought tolerant, and there is a variety that is resistant to taro leaf blight that has been identified and grown at the MoA Koronivia Research Station in Suva, Fiji.

Project purpose

This project is part of a two-phased collaboration to understand the implications of climate change for root crops in the Pacific Islands region, and identify potential adaptation options. The results of Phase 1, which was a participatory project with root crop farmers, documented the observed and expected impacts of climate change on root crop farming and value chains, with a focus on experiences in the four growing regions in Fiji (APCP and PHAMA Plus 2020). It enabled further collaboration between the APCP, Fiji Ministry of Agriculture, and the Pacific Community (SPC) Centre for Pacific Crops and Trees (CePaCT) to deliver Phase 2. Phase 2 included screening drought-tolerant taro varieties and field trials of a range of farming practices and crop varieties to determine their climate performance. Noting that the demonstration only collected data for one season so cannot be correlated to long-term climate change, but trialed climate-smart farming practices identified in Phase 1 as having the potential to address climate change impacts on root crops (taro).

<u>Phase 1</u> identified potential climate change impacts on root crop value chains in Fiji and possible adaptation interventions to minimise these impacts (APCP & PHAMA Plus 2020).

<u>Phase 2</u> conducted on-ground activities to demonstrate farming practices that have the potential to minimise climate impacts on taro crops and protect productivity and profits. It aimed to trial climate-smart farming practices identified in Phase 1 as having potential to address climate change impacts on root crops (taro), and support dissemination and awareness of results in Fiji and more broadly in the Pacific. The demonstration farms aligned with parallel activities undertaken by CePaCT to conduct greenhouse screening of different taro varieties under drought conditions to identify high-performing varieties.

The project goal was: *To value-add to the outcomes of the Phase 1 case study that used current downscaled climate science to collaborate with farmers and identify future impacts of climate change on root crop farming, and pilot climate-smart practices that have the potential to protect crop productivity (and profits) across the value chain*.

Objectives

The objectives of this study (Phase 2) were:

1. Pilot the recommended adaptations and interventions from Phase 1 with Fiji root crop (taro) farmers, and
2. Test the application of different farming practices and taro varieties to assist farmers and agribusiness stakeholders along the value chain to make informed decisions to reduce the impacts of climate change.

Project scope

In developing an understanding of climate change risks and vulnerabilities on root crop production and value chains, and identifying adaptation measures, the scope of this study has been guided by the interventions identified by root crop farmers. Phase 1 included consultations with root crop farmers, exporters and processors as key stakeholders, to collect information about potential climate impacts on root crop value chains. This information was synthesized into a comprehensive summary and options report. Scientific evidence, including climate projections (e.g. rainfall, ENSO cycles, temperature, extreme weather), climate risks (e.g. drought, flood, transboundary pests and diseases), and recent climate science research was used to inform the consultations and recommended options.

Phase 1 consulted with both men and women to ensure that all perspectives were considered, including the intersection between gender, disability and climate change, and the different roles of men and women in agriculture.

In making recommendations, the study examined other public and private sector examples that are already implementing climate-sensitive local solutions for root crop production and value chains and lessons from other development partners and their programs.

The results of Phase 1 in Fiji were extended to Phase 2 where identified climate-smart practices were applied on four demonstration voluntary farms using a family-farm based approach. The consistent message from the majority of farmers in all four growing regions on which solutions they would be willing to trial or demonstrate fell into three main categories:

1. Agro-forestry
2. Organic farming
3. Traditional (communal) farming practices.

Beneficiaries

The impacts of climate change on agricultural production and value chains are of great concern to all sector stakeholders in Fiji, with taro farmers already observing changes to seasons and climate that are affecting crops. The extensive knowledge and expertise of farming families can be applied to climate change mitigation, disaster risk reduction and adaptation strategies. There is also a need to ensure that mitigation and adaptation efforts consider the different roles of men, women and youth, and their unique experiences, knowledge and skills, to ensure climate change responses across the value chain are more socially inclusive and gender equitable.

This project partnered with farming families active in growing taro crops in four growing regions of Fiji, building on the networks from Phase 1. Engagement with Fiji farming families in Phase 1 reached over 200 people representing farming communities in four growing regions on three islands, as well as exporters and processors. Phase 2 continued this engagement, working with taro farmers across Fiji, extending the results of Phase 1 and trialling selected climate-smart practices. The results are being shared across farming families in the growing regions, through Ministry of Agriculture extension officers, and eventually, to other taro growing nations in the Pacific Islands region.

Climate-Smart Taro Farming

Demonstration farm sites

The results of Phase 1 were extended through Phase 2 at demonstration voluntary farms in the four main root crop growing regions of Fiji – Namosi, Naitasiri, Savusavu and Taveuni (Figure 1).

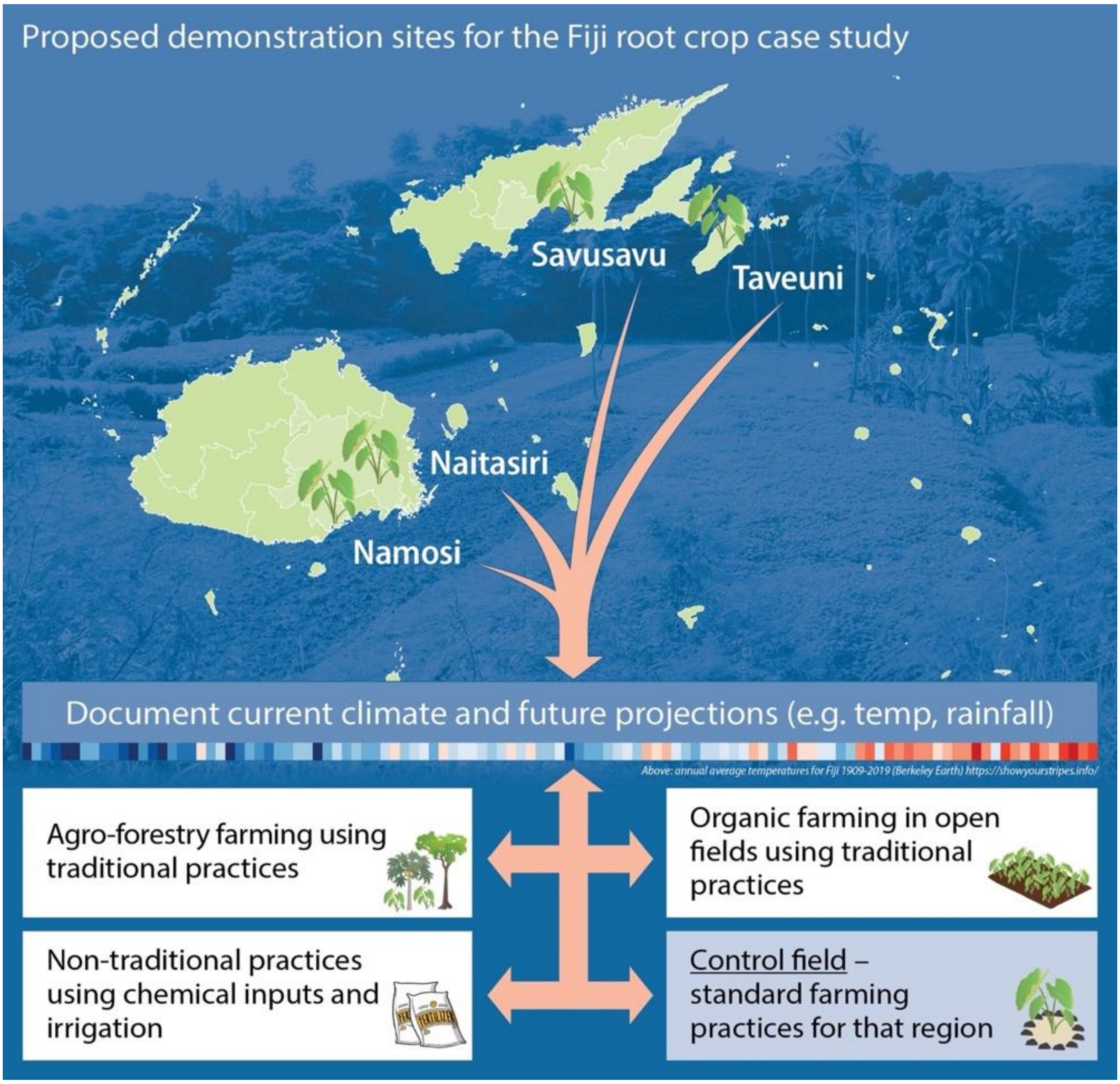

Figure 1. Overview of project sites and agricultural practices that will be tested as part of the study.

Taro varieties

The MoA Research Division supplied local disease-resistant varieties of taro (grown to be tolerant of taro leaf blight; Tarova loa, vula and damu) from the Koronivia Suva research station. The main export variety (Tausala ni Samoa) was also grown on the plots to compare performance against the farmers usual variety. Each variety of taro produces different yields and time to harvest maturity under ideal growing conditions. For example, Tausala ni Samoa is one of the highest yield varieties, producing between 13.3 and 19.9 t/ha (Vilsoni 1993). To minimise the effect of different growth and maturity rates, Tausala ni Samoa was grown in three of the four demonstration farms (except Savusavu due to biosecurity protocols), and on all four demonstration plots. The demonstration farm at Savusavu planted Uronivonu on all four plots. Between 150–200 seedlings were planted per demonstration plot, with a total of 600–800 seedlings planted on each farm.

The greenhouse trials at CePaCT focused on validation of a screening method of 16 local and export varieties of taro (*Colocasia esculenta*) for water-stress response and potential drought tolerance. The results of the greenhouse trials are available in Sukal et al. (2022), and found that five varieties (Tausala ni Samoa, Jabeni, Tarova Vula, Matadrala and Sikavi Loa) showed the highest water use efficiency. Four of the same varieties (excluding Jabeni) also had a lower stress index, suggesting that they could potentially be drought resistant.

The taro varieties grown at the demonstration sites were also shared with CePaCT for screening under specific growing conditions to determine varietal productivity differences. This information will be archived with the CePaCT genetic material bank in order to identify optimal varieties to propagate under specific conditions. The screening information also provides important parameters to validate the APSIM taro model (developed by ACIAR) and allow the production of future growth scenarios for taro.

Volunteer farmers

The study was delivered through partnerships with volunteer farmers and the Fiji Ministry of Agriculture, using existing extension networks to pilot agro-forestry, traditional, organic, and non-traditional practices (with chemical inputs and/or irrigation). Many farmers at Phase 1 workshops volunteered to be part of the demonstration and were approached to participate in Phase 2.

The demonstration farms in each region were volunteers selected based on the knowledge and networks of the Provincial extension officers. Meetings with these farmers were held to explain the approach and the climate-smart practices to be trialled. The demonstration farms were at Naitasiri Province in Lomaivuna Sector 2 (17°54’49.4” S, 178°24’24.0” E), Namosi Province in Wainimakutu village (17°57'50.1" S, 178°04'17.9" E), Taveuni in Masasa, Welagi (16°42’50.1” S, 179°54’08.4” W), and Savusavu in Navakaka village, Navatu (16°43'28.9"S 179°28'14.2"E) (Figure 2). A letter of agreement between the farmers and MoA was also signed.

Figure 2. Location of the four demonstration farms (image source: Google Earth)

Farming practices

The consistent message from most farmers in all four growing regions on which solutions they would be willing to trial or demonstrate fell into three main categories: (1) Agro-forestry, (2) Organic farming, and (3) Traditional and communal farming practices. These farming practices have been promoted as eco-smart and climate-resilient methods in the recent manual for farmers (McGregor and Taylor 2022). The Fiji Ministry of Agriculture also recommends the use of more intensive farming practices in some circumstances, being the application of chemical fertilizers and pesticides on fields during specific taro growing periods. This was therefore the fourth farming practice included in the demonstration farms.

Each demonstration farm planted four plots in February 2022 that were approximately 16 m x 16 m (256 m^2 each or 1,024 m^2 total area) and trialled four different taro farming treatments:

1. ***Organic*** (use of compost, bio-digester, organic fertilizers, i.e. poultry manure)
2. ***Conventional [non-traditional]*** (use of chemical inputs [nitrogen, phosphorus and potassium] and urea application) (MoA recommended practice)
3. ***Traditional*** (use of green mulch, compost, mixed/inter cropping, cover crops, sloped land management practices)
4. ***Control*** (current practices; the practice of the farmer in that growing region, documented during set-up of plots)

Materials applied on each demonstration farm were kept consistent, where possible (Table 1).

Table 1. Demonstration taro plot treatments and materials applied.

Treatment	Seedlings	Fertiliser	Compost	Other practices
Organic	150-200	Mineral fertilizer – Alroc #3 at 7.68 kg/plot; 8 bags/plot poultry manure (Naitasiri & Namosi)	Green mulch	Minimal tillage
Conventional	150-200	6.25 kg NPK (13:13:21) 2.5 kg urea (5 & 10 weeks); 8 bags/plot poultry manure (Naitasiri & Namosi)	N/A	Tillage (Namosi and Naitasiri); Chemical weed control
Traditional	150-200	Mineral fertilizer – Alroc #3 at 7.68 kg/plot	Green mulch (all sites); MoA readymade compost (Naitasiri and Namosi); Rice straw mulch (Naitasiri)	Inter-cropping, no tillage; SLM using dadap trees (Taveuni)
Control (farmers usual practice)	150-200	Details recorded at each demonstration farm: 1. *Namosi-Wainimakutu* – use of poulty manure, chemical fertilizers and urea with chemical weed control, tillage. 2. *Naitasiri, Lomaivuna* – use of growth formula (20ml/20L water) for a 30 second dip of planting materials before planting and Teitei blend mineral fertilizer (25g/plant) at planting. Weed control with chemical (glyphosate), and tillage. 3. *Taveuni, Masasa, Welagi* – use of chemical fertilizers. Mulched with dead plant material from chemical weed control (glyphosate). 4. *Savusavu, Navakaka* - no fertilizer used; mulched with dead plants from spraying before planting and weeded grass/weeds.		

Each demonstration farm included 4 plots (see Table 1) and volunteer farm families were provided with agronomy support for establishing the plots and maintaining them. This included provision of agronomic inputs (e.g. poultry manure), skills and planting material as needed. A control farm plot using the usual farming practices for that farm in that growing region was also part of the study, as the control plot.

Data collection

Climate conditions (total daily rainfall, maximum and minimum daily air temperature) were collected from four automated weather stations (one per demonstration farm) maintained by the Fiji Meteorological Service[1] throughout the study. These variables were chosen since temperature and rainfall have been shown to influence the growth and quality of taro (Crimp et al. 2017) and are key growth parameters. Climate conditions were supplemented by anecdotal updates on flood and high wind conditions from farmers.

[1] https://www.met.gov.fj

Climate conditions for Navakaka village, Savusavu were collected from the Savusavu Airstrip synoptic weather station (Station ID: V69831) located in a narrow valley running north/south on a peninsula extending westward from the Savusavu Jetty. The weather station is located at the southern end of the airstrip (16°48’22” S, 179°20’34” E), 16 m above mean sea level, and approximately 16.3 km southwest of the Savusavu demonstration farm.

Climate conditions for Masasa, Welagi, Taveuni were collected from the Matei Airfield synoptic weather station (Station ID: W66500) located on the northern tip of Taveuni Island on the Island’s airstrip (16°41’17” S, 179°52’50” W). The weather station is 3 m above mean sea level and is located approximately 3.4 km northeast of the Taveuni demonstration farm.

Climate conditions for Wainimakutu village, Namosi were collected from the Tokotoko weather station (Station ID: V88214) located on the Navua flats about 0.5 km from the main highway on the Suva side of the Navua Bridge (18°13’07” S, 178°10’22” E). The weather stations is 2 m above mean sea level and approximately 29 km south southwest of the Namosi demonstration farm. Unlike Wainimakutu village, the Tokotoko weather station is located on flat, exposed, coastal land, so that climate data may not be entirely consistent with conditions experienced in Wainimakutu village during the study period. However, given the inconsistency in data from surrounding weather stations (e.g. Nabukelevu Station), the Tokotoko weather station was considered the most reliable for the study.

Climate conditions for Lomaivuna Sector 2, Naitasiri were collected from the Lomaivuna weather station (Station ID: 78832) located on the Lomaivuna Plateau in the central eastern part of Viti Levu Island, Naitasiri (17°52'06.0" S, 178°21'05.0" E). The weather station is 131 m above mean sea level, approximately 7.6 km northwest of the Lomaivuna demonstration farm.

Weather reports from all four synoptic and/or weather stations are compiled every three hours. Data for Savusavu Airstrip Synoptic/Climate Station, Matei Airfield Synoptic/Climate Station and the Tokotoko Climate Station are managed by staff of the Fiji Meteorological Service, while Fiji’s Agricultural Department operates the Lomaivuna Climate Station.

Ministry of Agriculture Provincial extension officers attended the farms over the demonstration period to conduct weekly environmental data monitoring (light intensity (low, normal, high), soil temperature (°C), soil pH, humidity (%), and soil moisture (dry, normal, wet), using a 5-in-1 digital soil meter (model JHL9918), and monthly non-destructive collection of crop growth data (leaf appearance, plant height). For light intensity and soil moisture content, the soil monitoring device provides categorical values, i.e. low, normal, high, and dry, normal, wet, respectively. Study results below therefore use these categorical values, as opposed to numerical values. Environmental data was analysed against climate data (rainfall, air temperature) from the Fiji Meteorological Service for each growing region, and crop yield data collected at harvest.

Other information collected during the demonstration period included:

- Details of farming practices used, timing of planting and any issues experienced,
- Details of family roles, responsibilities and decision-making during the demonstration,
- Crop varieties/accessions being grown, and
- Date and conditions at harvest.

Taro Production and Climate Influences

Observed and projected climate for Fiji

Fiji is in the central western tropical Pacific region and as such experiences generally warm and humid conditions year-round, with a monsoonal season that drives annual wet and dry periods. Average annual temperature varies from year-to-year (e.g. 2011 warmer year, 1994 cooler year) and generally averages 23–25°C in the dry season (May-October) and 26–27°C in the wet season (November-April) (Fiji Meteorological Service). Average temperature in the Fiji region has risen by 0.7°C since pre-industrial times (1850–1900), and at a faster rate in recent decades (1980–2020), with a clear warming trend that has coastal areas warming faster. Annual average temperatures are projected to increase by another 0.6°C (between 0.3–1.0 °C) by 2030, 0.7–1.3°C by 2050, and by 0.7–1.9°C by 2070 (relative to 1986–2005) (BOM & CSIRO n.d.).

Fiji experiences large year-to-year variability in annual total rainfall, being wetter on the east coast and mountain areas. There is no real long-term trend in rainfall with projections that ongoing variability will continue for the next 10 years (2021–2030); and rainfall may decrease, increase, or not change. Beyond 2030, there is a range of possible changes in rainfall possible (long-term trends are unclear) with more extreme rainfall events expected (BOM & CSIRO n.d.).

While not considered in this study, other climate variables that may also impact on taro farming in Fiji include sea-level rise, that is projected to increase by 0.66 to 1.21 m by 2100 under a high emission scenario, and is expected to increase inundation of farm/growing areas in low-lying coastal areas. Inundation of coastal farms is also possible due to more intense storms and cyclones (BOM & CSIRO n.d.). Increasing salinity of soils and groundwater can impact taro and other root crops (Crimp et al. 2017) but was outside the scope of this study.

Taro growth requirements

Taro is generally a 9–10 month crop that grows best in wet, warm, humid environments, and most varieties are not drought tolerant. The introduction of irrigation has been shown to generate substantial yield gains (Crimp et al. 2017), which will be important under future projected climate change where drought periods are expected to become more frequent. While taro is a year-round crop when there is adequate moisture, the ideal planting window in Fiji is small, with September to November producing the best yields, November to December being the usual planting window, and all other planting windows resulting in yield declines under future climate change scenarios (Crimp et al. 2017).

Temperature increases affect both taro yield (e.g. above +3°C negative impact on taro growth) and harvest timing, since the plants grow faster and therefore mature and are ready for harvest earlier under increased temperatures (Figure 3). However, the plants product smaller taro crops under higher temperatures (Crimp et al. 2017, Taylor et al. 2016).

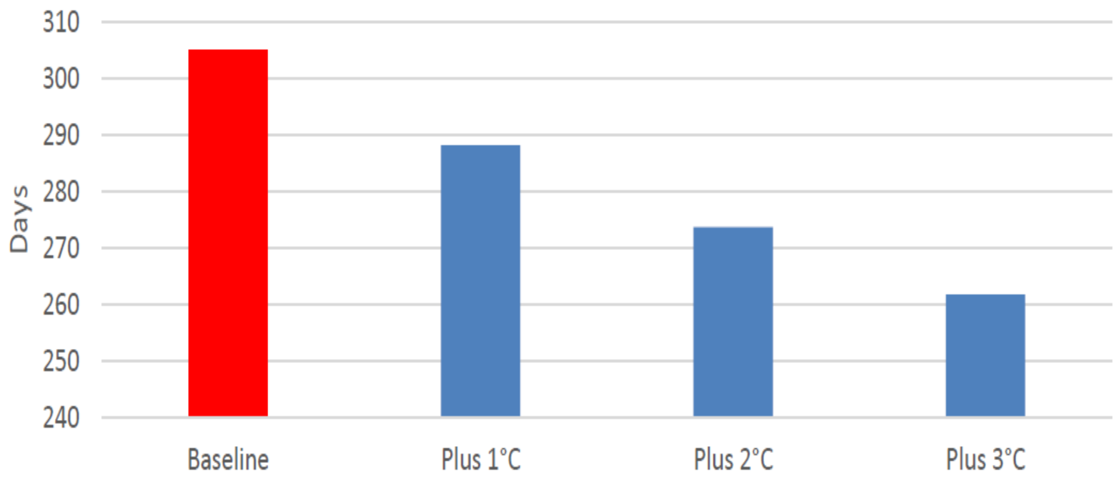

Figure 3. Taro growth trials in Suva, Fiji under different temperature conditions, and period to maturity for harvest (Source: Crimp et al. 2017).

Climate change impacts on taro production and value chains

A range of impacts on taro production and value chains are expected due to climate change, particularly from increasing temperatures and changing rainfall patterns, and include:

- Increased incidence of taro leaf blight due to ***increasing night-time temperatures*** (Taylor et al. 2016),
- Faster growth and smaller crops at maturity due to ***increasing daily maximum temperatures*** – with 30°C being a threshold that would be passed in many growing regions – which would affect growing conditions and decrease yields (Crimp et al. 2017),
- Earlier harvest timing due to ***increased temperatures*** (Crimp et al. 2017),
- Increasing reliance on fertilizer and pesticides (due to the combined effects of ***higher temperatures and rainfall*** increasing the risk of pests and disease, e.g. taro leaf blight and Pythium,
- Crops are vulnerable to ***flooding***, which damages plants and causes water-logging in soils (Taylor et al. 2016),
- ***Extreme heavy rain*** can cause soil erosion and physically damage crops (see Namosi case study),
- Some taro varieties are sensitive to ***low to moderate levels of salt*** in soils and groundwater (Crimp et al. 2017),
- Taro is sensitive to ***cyclones and strong winds*** that impact growth and damage plants,
- ***Heavy rain and severe storms and cyclones*** can also damage critical farm and processing infrastructure, as well as interrupt crop transport to market.

There are also possible benefits for taro production as a consequence of climate change. For example, an increase in rainfall might improve growing conditions in some areas, particularly those that are too dry to grow taro. And increased rainfall may benefit some varieties that prefer wet soils, such as giant swamp taro (*Cyrtosperma merkusii*).

Results

Establishing demonstration farms

The taro demonstration farms in the four growing regions were established in mid to late February 2022. This is later than the ideal planting season, however heavy rains from November 2021 to January 2022 and movement restrictions due to the Covid-19 pandemic, prohibited earlier planting. Importantly, taro can be grown year-round, especially in Taveuni and Savusavu, so the late planting did not compromise comparisons across plots with different farming practices or across growing regions. The period to harvest varied across the growing regions, from just over 6 months to close to 9 months, despite the taro varieties planted, although it is recognised that different varieties mature at different rates. The time to set up the demonstration plots was not significantly different across sites or compared to usual practices. A summary of the set-up details for each demonstration farm is provided in Table 2.

Table 2. Summary of dates and resources required to establish the demonstration plots in each growing region. N.d.= no data available.

Growing region	Planting date	Harvest date	Period to harvest	Taro varieties planted	People to establish	Time to establish
Savusavu	8 Feb 2022	24 Oct 2022	8 months 2 weeks	Uro ni vonu; Wararasa	8	8 hours
Taveuni	22 Feb 2022	1 Sep 2022	6 months 1 week	Tausala	7	8 hours
Namosi	10 Feb 2022	*n.d.*	*n.d.*	Tausala; Tarova TLB resistant varieties	6	1 hour
Naitasiri	11 Feb 2022	7 Nov 2022	8 months 3 weeks	Tausala; Tarova TLB resistant varieties	7	6 hours

Some challenges were experienced in the demonstration farms, and these were documented in this report, where relevant (e.g. see Namosi case study). In Taveuni, the continuous heavy rain encountered throughout the first 4 months of the trial may have contributed to the high incidence of taro corm rot in all four demonstration plots. Out of the 90 plants harvested from each plot, about 25% had corm rot. The heavy rains also promoted vigorous growth of weeds, which increased plot maintenance and corm rot. The Taveuni farm also experienced incidences of stealing, which is why harvesting was earlier than at other sites, yet the taro was of marketable sizes. At the Naitasiri site, there were challenges due to changes in Fiji MoA extension officers, resulting in soil condition data not being continuously collected for each plot and the details of farming practices at each demonstration plot not well recorded. At the Savusavu site, the destruction of part of a plot by stray cattle and rat damage was also evident.

Climate conditions during demonstration

During the demonstration growing period (March to October 2023), a range of climate variables were collected at the four locations – observed daily maximum and minimum temperatures, number of days exceeding 30°C, number of days exceeding 33°C, total daily rainfall, rainy days, and highest recorded daily rainfall (Table 3). Daily maximum and minimum temperatures were more stable in Savusavu and Taveuni than the other growing regions (Figure 4), with maximum temperatures averaging 29.5°C and minimum temperatures 21–22°C throughout the season. Higher and more variable temperatures were observed for Namosi, with an average maximum temperature of 30.1°C. Naitasiri experienced the coolest mean daily maximum (29.3°C) and mean daily minimum (20°C) temperatures of all the growing regions. Temperatures above 33°C were recorded during the growing season on 30 days in Namosi, four days in Savusavu, 14 days in Naitasiri, and zero days in Taveuni. This is notable due to the influence of increasing temperature on taro growth, yield and harvest timing.

Table 3. Key climate parameters and observations for March-October 2022 for the four locations

	Mean daily max temp (°C)	Mean daily min temp (°C)	No. of days exceeding 30°C (n)	No. of days exceeding 33°C (n)	Total rainfall (mm)	Rainy days (n)	Highest recorded daily rainfall (mm)
Savusavu	29.4	21.2	77	4	1296	153	111.5
Taveuni	29.5	22.3	69	0	1558	172	87.0
Namosi	30.1	21.8	99	30	1898	148	125.0
Naitasiri	29.3	20.0	89	14	2058	167	126.5

Patterns of total daily rainfall were relatively similar across the four growing regions, with all four locations receiving high rainfall throughout the growing season, with more rainy days and higher total daily rainfall recorded during the months of March, April, May and October (Figures 5, 6 and 7). Taveuni recorded the greatest number of rainy days during the growing period (70% of days had at least some rainfall), and Namosi the least. However, Namosi and Naitasiri recorded the highest total daily rainfall (most rainfall received in one day) at 125 mm and 126.5 mm, respectively, exposing demonstration farms to extreme rainfall that can cause flooding. The lowest total daily rainfall recorded was at Taveuni that received 87 mm in one day (Table 3).

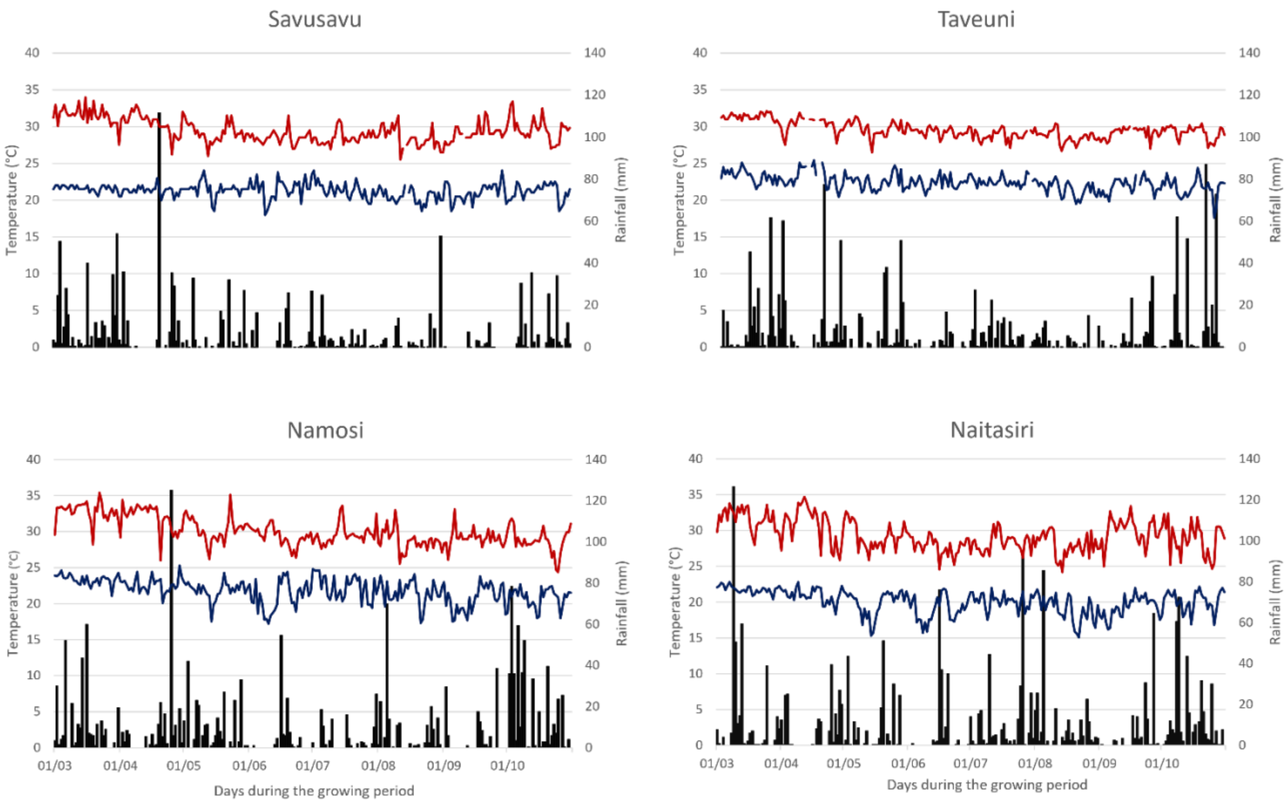

Figure 4. Daily maximum temperatures (red line), daily minimum temperatures (blue line) and daily total rainfall (black columns) for four locations for the growing period (March – October 2022). Data source: Fiji Meteorological Services.

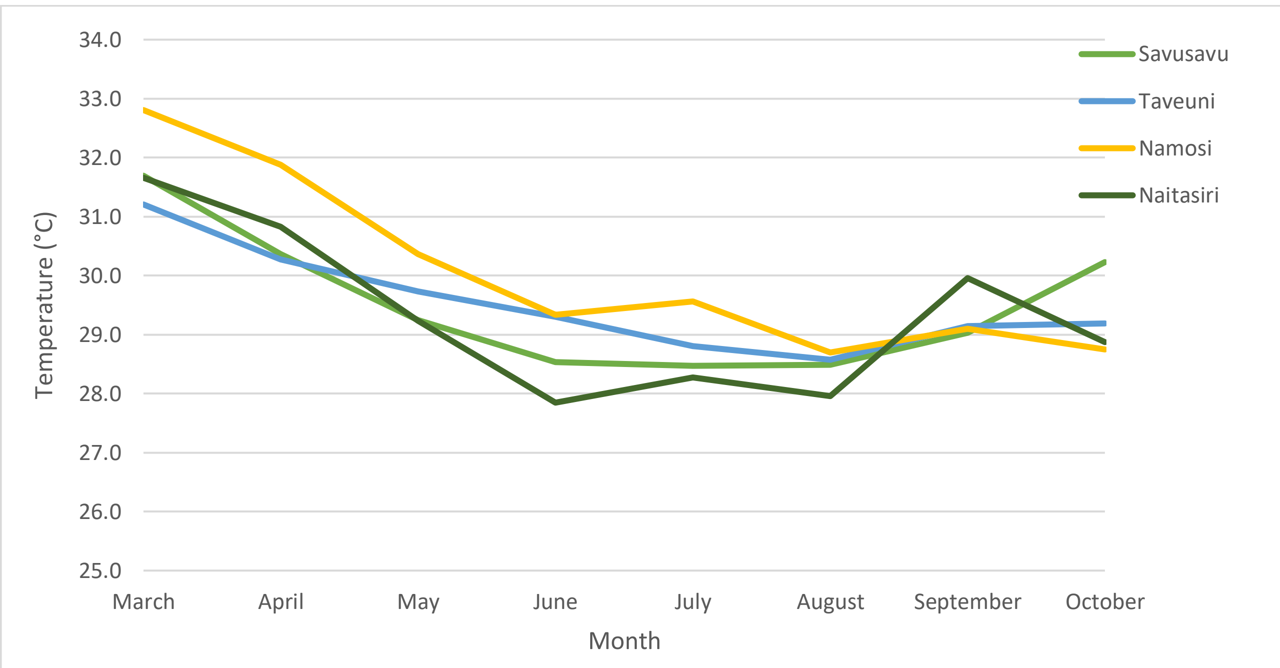

Figure 5. Average monthly maximum temperature for the four locations (March - October 2022)

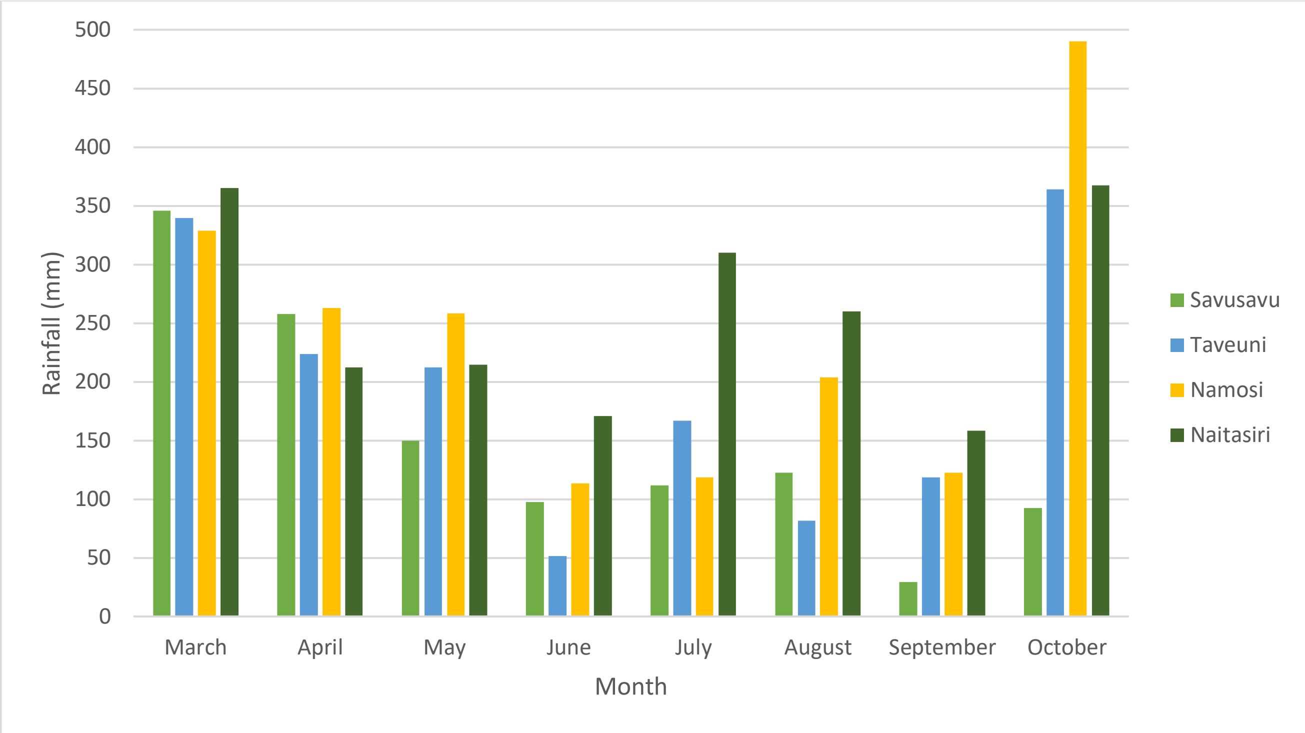

Figure 6. Total rainfall received per month for the four locations (March – October 2022)

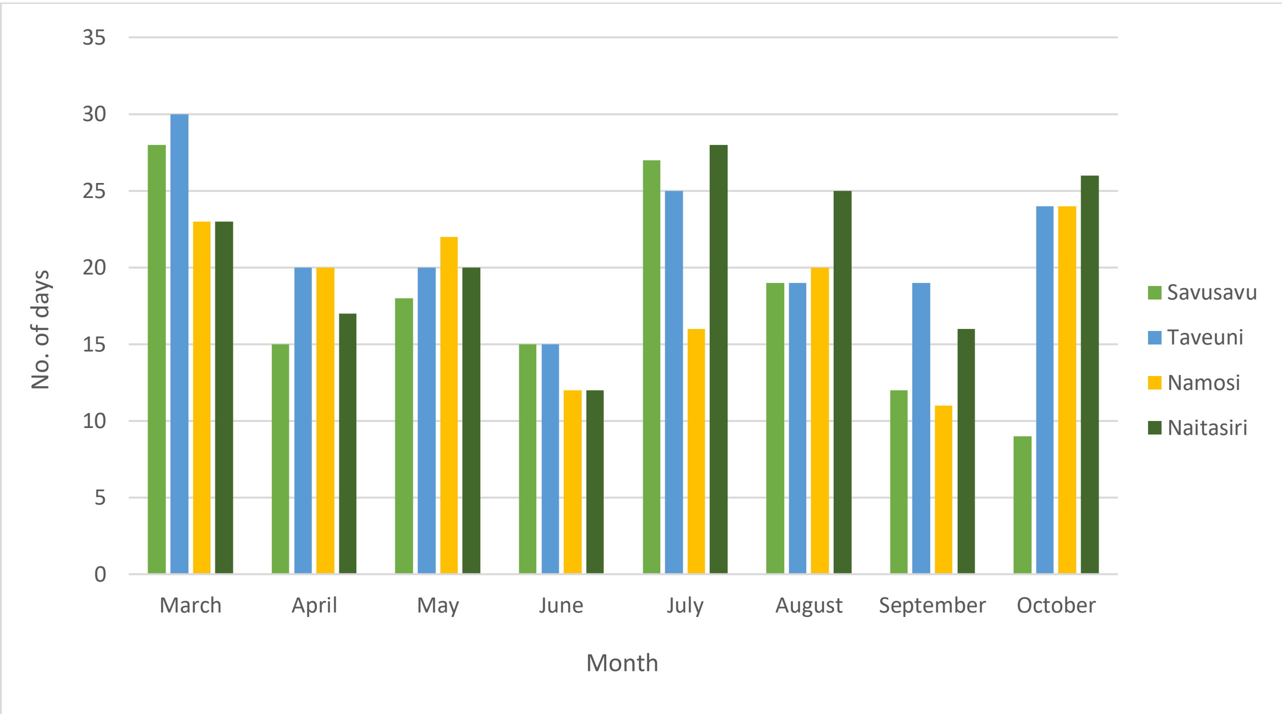

Figure 7. Total number of rainy days per month for the four locations (March – October 2022)

Soil conditions during demonstration

Mean plot-specific soil properties and parameters were recorded for each farming practice at three of the demonstration farms – Savusavu, Taveuni and Namosi – during the growing period (Table 4). Unfortunately, due to a change in personnel of Fiji MoA extension officers, soil condition data was not continuously collected for each plot at Naitasiri, and the details of the farming practices at each demonstration plot were not recorded. Therefore, the soil data for Naitasiri has been excluded and the following results focus on the remaining growing regions.

Across the three locations, higher soil pH, humidity and moisture content were recorded at Savusavu, and Namosi recorded much higher soil temperatures relative to Savusavu and Taveuni. Interestingly, Namosi, with its more extreme climate conditions (i.e. higher temperatures and more extreme rainfall events), recorded lower soil pH, higher soil temperature, and much lower soil humidity.

Table 4. Mean soil pH, temperature, humidity, light intensity and moisture content for each demonstration plot in each growing region during the growing period (March – October). Famers' own=control plot.

	Farming practice	**Soil pH**	**Temperature (°C)**	**Humidity (%)**	**Light intensity**	**Moisture content**
Savusavu	Organic	6.7	26.6	71.8	Normal	Normal
	Traditional	6.8	25.9	71.3	Low	Normal
	Conventional	6.9	26.1	72.8	Low	Normal
	Farmers' own	6.9	26.3	73.7	Low	Normal
Taveuni	Organic	6.4	25.3	65.4	Normal	Dry
	Traditional	6.4	25.8	66.3	Normal	Normal
	Conventional	6.7	26.8	71.8	Low	Normal
	Farmers' own	6.4	25.8	67.8	Normal	Dry
Namosi	Organic	6.0	30.4	52.0	-	Normal
	Traditional	6.0	31.3	53.5	-	Normal
	Conventional	6.3	29.3	50.9	-	Dry
	Farmers' own	6.5	29.9	56.5	-	Normal

A curvilinear regression analysis (using a polynomial model, order number 6) was performed to understand the relationship between environmental data and crop yield. Of all of the soil variables, soil moisture showed the closest relationship with crop yield size, producing an R-squared value of 0.98 (Figure 8). Results suggest that crop yield is greatest under normal to slightly dryer soil moisture conditions. This finding is consistent with the CePaCT greenhouse trials (discussed in Introduction) and has important implications for taro growth under extreme weather conditions, suggesting that both drought and water-logged soils (due to high rainfall) can negatively impact crop yield. This finding also confirms the importance of keeping soils moist, either through mulch or canopy cover, both of which were used in traditional farming demonstration plots in the four growing regions.

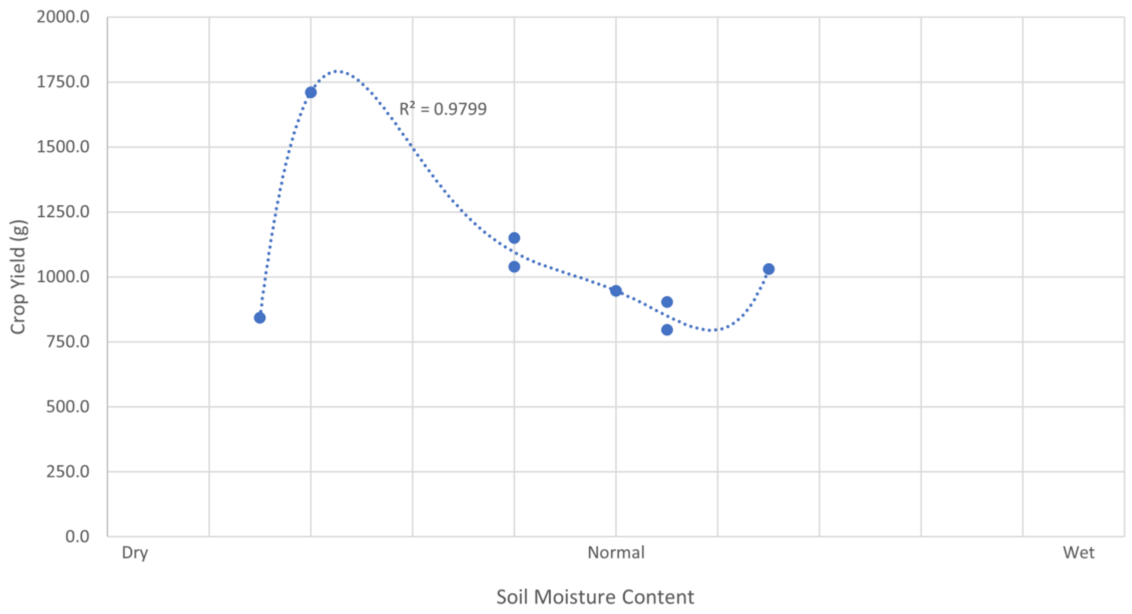

Figure 8. Relationship between crop yield at harvest and mean soil moisture content throughout the growing period.

Namosi flooding case study

The demonstration farm in the Namosi growing region was located near Wainimakutu village on flat cleared land tilled by a tractor on the riverbank of the Namosi River. The farmer planted mixed varieties of plants, being taro leaf blight resistant Tarova and the export variety Tausala in the traditional plot, organic plot and conventional plot. The control (farmers' own practices) plot had the export variety Tausala planted. The four demonstration plots were planted on 10 February 2022 and took six people 1 hour to set-up.

Taro crop growth data collected at 5 and 10 weeks into the growing period recorded greatest average plant height for the organic plot (both varieties) in week 5, and the organic plot (both varieties) and traditional plot (Tarova variety) in week 10. The greatest seedling (sucker) numbers (per m^2) were recorded in the organic plot (both varieties) and the traditional plot (both varieties), and no suckers grew in the conventional or control (farmers' own) plots (Table 5).

Table 5. Average plant height and sucker numbers for the four different farming practices at the Namosi demonstration farm (weeks 5 and 10).

		Average plant height (cm)		**Number of suckers (per m^2)**	
Farming practice	**Taro variety**	**Week 5**	**Week 10**	**Week 5**	**Week 10**
Organic	Tausala	45.33	56.67	0	0.5
	Tarova	41.67	56.67	0.25	0.5
Traditional	Tausala	36.33	41.67	0.25	0.25
	Tarova	34.67	51.67	0.25	0.25
Conventional	Tausala	40.67	46.67	0	0
	Tarova	39.00	43.33	0	0
Farmers' own (control)	Tausala	35.25	46.25	0	0
	Tarova	40.67	46.67	0	0

Following severe flooding in the Namosi region in mid-October, the taro crop was washed away and only a few suckers remained. October was the wettest month in Namosi with 24 days of rainfall, receiving total rainfall of 490 mm for the month, and having several days of high rainfall (e.g. 125 mm).

More extreme conditions were observed during the demonstration period in Namosi. For example, Namosi recorded the highest mean maximum temperature, the greatest number of days exceeding 30 and 33°C, a high daily rainfall of 125 mm and a relatively large amount of rainfall throughout the demonstration period yet the lowest number of days with rain. The extreme rainfall in October eventually resulted in flooding of the demonstration farm on the riverbank and crop loss. Given Fiji's climate change projections that these extreme conditions may become more frequent, the Namosi case study demonstrates the risks of planting on riverbanks and on cleared land. It also demonstrates that while the organic and traditional farming practices were showing the most promise in terms of taro crop growth and potential yield, the need to apply flood management practices alongside these traditional and organic practices will become more important to build climate resilience. It may also support anecdotal evidence from farmers that seasons are shifting and planting and harvest timings may also need to shift to adapt to these changes and avoid total crop losses.

Taro production and sales

Data collected at the three demonstration farms that harvested their taro show differences between the average taro size recorded for each farming practice (Figure 9). Average taro sizes ranged between 800 and 1,000 g in Savusavu, 800 and 1,700 g in Taveuni, and 900 and 1,900 g in Naitasiri. The relationship between the time to maturity and yield of different varieties is most relevant in Savusavu where the Uronivonu variety was grown, but all other demonstration farms grew Tausala ni Samoa so results could be compared.

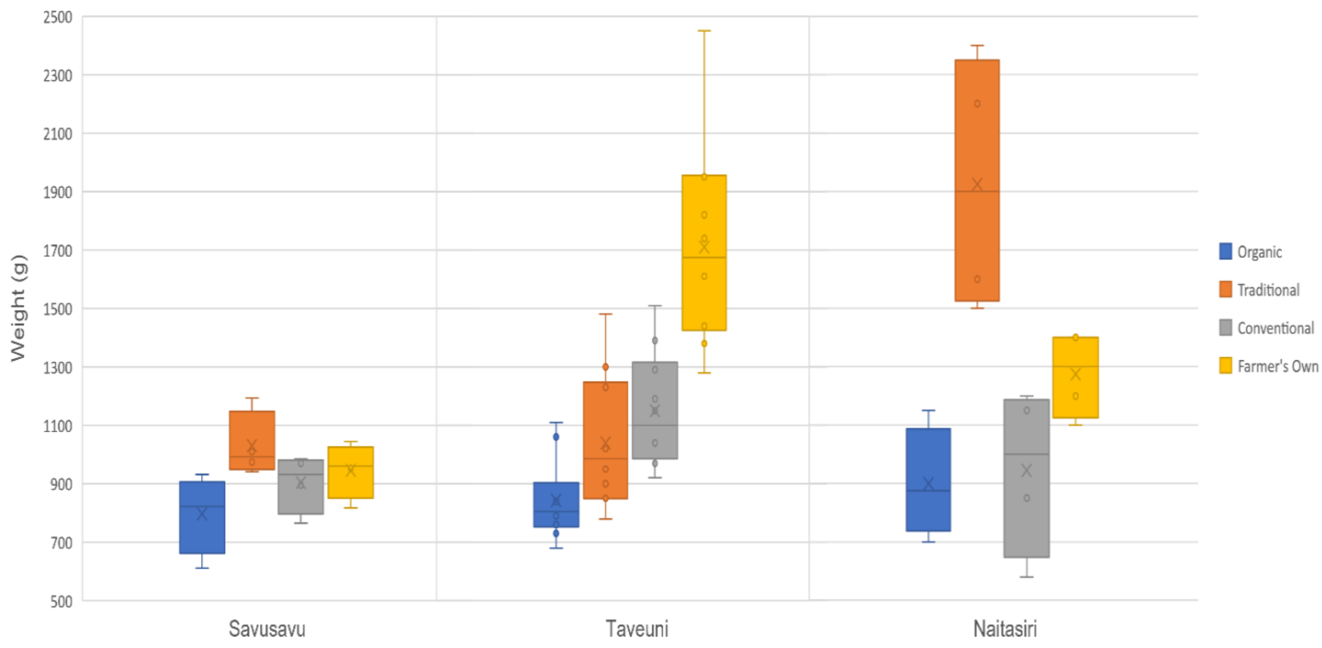

Figure 9. Average taro size at harvest time for each farming practice at Savusavu, Taveuni and Naitasiri. Whiskers show lowest and highest average size recorded for each farming practices.

Traditional farming practices produced larger taro sizes in Savusavu, with organic farming producing the smallest sizes. However, part of the organic plot was damaged by stray cattle and rats, especially the Uronivonu taro variety, which likely accounts for the smaller sizes. In Taveuni, the farmer's own practices produced significantly larger taro sizes, with mean sizes greater than the highest sizes recorded for all other practices (Figure 10). The farmer's own practices were a combination of traditional and organic practices (green mulching) and conventional practices (chemical fertilizer). In Naitasiri, traditional farming practices produced significantly larger taro sizes than all other practices, with organic and conventional farming practices producing some of the smallest sizes recorded at the location. However, the taro crop from the organic plot at Naitasiri was affected by taro beetle, which explains the smaller sizes.

Figure 10. Taveuni taro crop from the organic (left) and farmers' own demonstration plots.

The value of taro crops was not recorded for each different farming practice (plot) but was recorded collectively for all product at each of the three growing regions that harvested their crop (Figure 11). Notably, Taveuni had the highest amount of market-grade taro[2] and also received the highest price per kg (FJD 3.80) and therefore the greatest total sales value. While both Savusavu and Naitasiri produced mixed taro varieties and received lower prices per kg (FJD 1.50 and FJD 2.80, respectively). This may be an indication of the variety of taro produced as well as the quality and quantity, but there is insufficient data to determine this. Noting that preferences for taro varieties in the local market are individual, with eating quality depending on each consumers preferences. In Naitasiri, all the export variety (Tausala ni Samoa) taro harvested were of market-grade quality, but the mixed variety (TLB resistant) was not purchased by the exporter and the farmer had to look for another local market.

[2] Taro quality for export is a uniform oval shape, firm, without any blemishes or soft spots, and free of root hairs. Basal stems and petioles or stalks should not be more than 5 cm. Weight preference is 1–3 kg, however, corms above 750 g meeting all other requirements are also accepted for export.

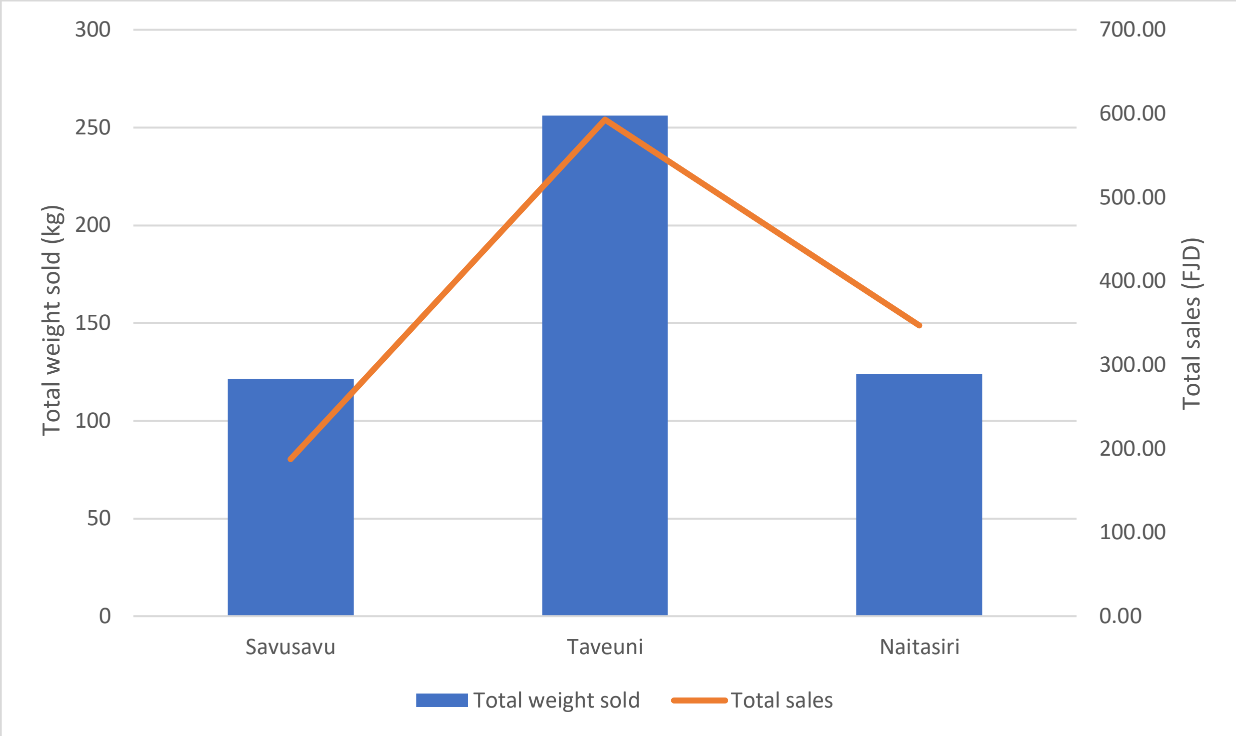

Figure 11. Market sales (in weight and value) of taro from the three demonstration farms that harvested a crop.

Climate-smart practices

The demonstration identified potential climate-smart practices to address expected climate change impacts on taro farming. Harvest sizes were relatively high for all farming practices in Taveuni, which experienced a more constant climate suited to growing taro; low maximum temperatures (below 30°C), average rainfall throughout the growing period and no extreme rainfall events. While all farming practices produced large market-grade taro, the farmers' own practices performed the best, and were a combination of traditional and organic practices (green mulching) and conventional practices (chemical fertilizer). This is why Taveuni farmers tend to grow taro year-round and is supported by the higher weight sold and sales prices received.

Traditional practices that use green (and dead plant material) mulching, poultry manure, inter-cropping, and minimal tillage produced larger taro in Savusavu and Naitasiri, with significantly larger crops in Naitasiri. This supports anecdotal evidence from farmers consulted in Phase 1 that traditional farming practices are effective at addressing climate change and should be re-introduced throughout Fiji root crop growing regions.

Climate change projections are that Fiji will experience conditions similar to those at Namosi in the future (i.e. higher maximum and minimum temperatures and more extreme rainfall events). This will reduce the area suitable for growing high quality and quantity taro in many parts of Fiji. Using Savusavu and Naitasiri as examples of changing climate (e.g. more extreme rainfall but less total rainfall, more hot days over 30°C and 33°C), some farming practices are more climate-smart than others. Under such conditions, traditional farming practices, using poultry manure rather than chemical fertilizers, applying green mulch, mixed or inter-cropping, use of SLM and minimal tillage are likely to produce larger taro, or at least market-grade sizes and quality.

Accordingly, while conventional farming practices with chemical inputs may be effective today, they will become less effective over time as changing climate conditions continue.

The Namosi case study highlights the importance of also considering flood management practices to buffer against extreme rainfall events, which are predicted to increase in frequency and intensity in the future. Such practices should include, not planting in riparian or flood zones, avoiding planting on steep slopes, no tilling, and using agro-forestry, mixed or inter-cropping to protect root crops from heavy rains and floods. These practices were identified during Phase 1 by farmers as being important climate adaptations, and supports the need to draw on traditional knowledge to minimise the impacts of future climate change (Figure 12).

Figure 12. Two possible futures for farming in Fiji showing the impacts of climate change on farms where no adaptations are applied (left) and where agro-forestry, inter-cropping and SLM are applied. Source: APCP & PHAMA Plus 2020

Conclusions

Noting that the demonstration only collected data for one season so cannot be correlated to long-term climate change, the study trialed climate-smart farming practices identified in Phase 1 as having potential to address climate change impacts on root crops (taro).

While the usual planting window for taro in Fiji is November to December, changing climate conditions are impacting the ability to plant when heavy rains start early. Consideration of a shifting rainy season may require earlier planting times, and studies have suggested that September to October may be the ideal window under future climate change (Crimp et al. 2017).

And this study has shown that later planting (February) may also be an option, and does not significantly compromise taro quantity and quality, with farms still producing market-grade crops.

Climate conditions during the demonstration period varied across the growing regions, with Savusavu and Taveuni experiencing conditions more suitable for taro growth, and Namosi experiencing higher and more variable temperatures. Naitasiri experienced the coolest daily maximum and daily minimum temperatures of all the growing regions. All four regions received high rainfall throughout the growing season, particularly in March, April, May and October, and Namosi recorded the highest number of rainy days during the growing period, ultimately resulting in flooding and a loss of the taro crop. These conditions are reflected in the taro crop harvested, with Savusavu and Taveuni producing the most market-grade taro.

Differences in soil properties (pH, temperature, humidity) were more significant across growing regions rather than across different farming practices, suggesting climate or other region-specific environmental trends may be more influential on soil properties that localised farming practices.

Studies have shown that higher temperatures can produce smaller crops and reduce growth time to harvest of taro from 10 months to 8 months in Fiji (Crimp et al. 2017), and to as short as 6.4 months in other Pacific countries (Miyasaka et al. 2003). This has been supported by anecdotal evidence from taro farmers in Fiji (APCP & PHAMA Plus 2020). All demonstration farms in this study had reduced harvest periods, with Taveuni being the shortest at 6 months, 1 week, and all sites harvesting before 9 months of growth. Most taro produced, however, was of a size and quality that could be sold as export grade, and some for local markets. This supports the suggestion that taro will grow faster under climate change, with shorter harvest periods.

Namosi provided an example of the potential impacts of future projected increases in rainfall extremes, particularly in flood-prone areas, such as riverbanks. The total loss of the taro crop at the Namosi demonstration farm due to flooding, confirms the importance of considering changing rainfall patterns when selecting farm plots to plant, and implementing climate adaptations to minimise flood impacts, such as agro-forestry, mixed or inter-cropping, minimum tillage, and slopped land management practices. However, any maladaptation, such as expanding farming into virgin forest areas, to avoid flooding or other climate impacts, should be avoided. Controls on farming virgin forests and steep land should be accompanied by awareness and training on sustainable agriculture and sloped land management practices.

Taro production between the four farming practices trialled was variable across the growing regions, with traditional or farmers' own practices (using a mix of traditional/organic and conventional practices) performed best under the climate conditions experienced. Notably, climate change projections are that Fiji will experience conditions more like those at Namosi in the future, which will reduce the area suitable for growing taro in many parts of Fiji. Under such conditions, traditional farming practices, using poultry manure rather than chemical fertilizers, applying green mulch, mixed or inter-cropping, use of SLM practices and minimal tillage are likely to produce market-grade taro. While conventional farming practices with chemical inputs may be effective today, they will become less effective over time as changing climate conditions continue.

Some demonstration farms experienced issues with pests and disease (e.g. taro corm rot, cattle and rats), particularly in the organic plots. Pests and disease are expected to increase under future climate change as temperatures and rainfall combine to create ideal conditions. Therefore, consideration of which organic farming practices are suitable, and incorporating traditional knowledge and practices that address these issues are important to minimise climate change impacts in the future. The project results provide insight into likely climate-smart practices, and future targeted studies with controlled inputs in each growing region or greenhouse conditions, could provide specific recommendations for each region.

The value of the taro produced in the three demonstration farms that harvested a crop varied significantly across the growing regions. Negotiating fair and equitable farm-gate prices and access to export markets is key to maintaining the value chain in Fiji particularly as climate change impacts production. While farmers can apply adaptations to minimise climate impacts, and this study showed that there weren't significantly extra time or people requirements, the economic value and incentive to continue taro farming also depends on external market drivers.

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APPENDIX A: Protocol for Taro Demonstration Plots

A. Demonstration Treatments (4)

i. Farmers current practice (control)
ii. Organic farming
iii. Conventional – MoA Recommended
iv. Traditional with slope land management (SLM)

B. Plot Details

i. Gross plot size – 16 m x 16 m/plot for each of 4 plots
ii. Total Demonstration area = 1,000 m^2
iii. Farmers variety and the TLB resistant taro varieties will be equally planted in each plot.

Selection of demonstration plots should focus on already farmed land and not new forest land that requires clearing of forest or native trees/vegetation to prepare for planting. Once seedlings are planted and the demonstration has started, the practices should remain as documented, even if conditions change. For example, if there is an extended dry period, no hand watering or irrigation should be used if this is not the usual practice of the farmer or part of the treatment.

C. Measurements/Recordings

- Farming practices documented before planting
- Weekly – soil pH
    - air and soil temperature (°C)
    - soil moisture
    - humidity
    - light intensity
- Monthly: - Plant heights
  - No. of fully opened leaves
  - No. of suckers
  - (*Number of plants for sampling – 10 per plot)?*
- 2 Soil Samplings – 1 before planting & 1 at harvest
- 2 Soil biology data – 1 at planting & 1 at harvest
- Yield at Harvest (Marketable & non-marketable yield)
- Management rating of sites (1 – worst; 5 – best)
- Pest & Disease incidences; (Rots, Mealy bugs, etc…)
- Download Fiji Meteorological Services weather data for temperature and rainfall

D. The 4 sites

1. Naitasiri – Lomaivuna Sector 2
2. Namosi – Wainimakutu Village
3. Savusavu – Navakaka Village, Navatu.
4. Taveuni – Masasa, Welagi.

Notes:
***** Treatments** will be applied before planting (poultry manure (pm) 2 weeks prior), at planting and as when recommended during weekly field recording days)
******Field maintenance** will be the farmer's responsibility
*******Soil & Weather data** weekly recordings will be done by MoA Locality Officers

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