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Lalit Kumar *Editor*

Climate Change and Impacts in the Pacific

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Preface

Pacific island states are generally small in size with a limited and narrow range of natural resources. Due to their small sizes, generally low elevations and isolation, they are highly vulnerable to natural environmental events. Many of them fall directly in the paths of tropical cyclones. Floods, tropical cyclones, droughts and storm surges have become a part and parcel of these people. However, over many generations, these island people have adapted well to the natural events that are quite regular and over which they have no control. The people of the Pacific have become accustomed to these, and now, such events are inseparable from their lives. As if such challenges in life were not sufficient, we now have a new entrant that is causing havoc in many small islands and is destroying lives and livelihood. This is an event for which humankind is almost totally responsible and over which they have a large degree of control. Yet humankind still refuses to take responsibility for this, and any action to limit its damage is lethargic at best. What we are talking about is climate change.

Climate change and its related issues have become critical for the Pacific islands and its people. While many of the larger countries are modelling what will happen in their surroundings in 50–100 years' time, the people of the Pacific have to deal with it here and now. Communities are being relocated, land is being purchased in other countries to settle entire populations, salt water intrusion and salinity are leading to loss of limited arable land on many islands, crops that have been part of their diet can no longer be cultivated due to rising water tables, and extreme events such as more powerful tropical cyclones are ravaging villages. Yet many of us continue to deny that climate change is a reality and, unfortunately, the leadership of some of the most powerful nations on the planet are providing fuel to such groups. The real-world evidence seems to be having no impact on such thinking. We have pictures of graveyards that are now offshore; who in their right minds would select such locations to have graveyards? We have pictures of houses that have waves crashing into them at every high tide; we have pictures of houses that are almost permanently in the sea now; we have pictures of taro farms regularly inundated by sea water; and the list goes on.

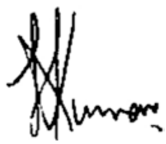
With the people of the Pacific becoming more vocal about this issue in recent years, the issue of climate change impacts in the region has garnered greater attention. Research on likely impacts and best adaptation practices are on the rise. More international support and funds are flowing into the region to support people to deal with the issue of climate change. However, the publicly available information on climate change, its impacts in the Pacific and means of adaptation are few and far in-between and spread over a wide range of scientific publications, web pages and grey literature. One of the objectives of this book is to provide a comprehensive overview of climate change issues in the Pacific, what the people are dealing with now, how susceptible are islands to climate change impacts and how many islanders are adapting to the changes brought about by climate change.

The book starts with a comprehensive overview of climate change and the Pacific, summarising what research has been undertaken and what are the projections for this part of the world over the next 50–100 years. Chapter 2 describes the islands in the Pacific, their settings, distribution and classification. Climate change scenarios and projections for the Pacific are discussed in detail in Chap. 3. This chapter looks at observed climate in the Pacific and compares it with future projections under various climate change scenarios. In Chap. 4, we propose an index that is a relative measure of susceptibility of individual islands in the Pacific to physical change under climate variables. This chapter describes both the physical attributes of islands and environmental variables such as tropical cyclones and significant wave height and how these could be combined to provide information on relative risks of islands. This idea is further refined to a more local (finer) resolution in Chap. 5 where methods are developed for downscaling from whole-island risk assessment to landform susceptibility. A selection of islands from the Pacific is used to demonstrate how this could be incorporated in more local landscape-level risk assessment. Chapter 6 reviews tropical cyclones, its natural variability and potential changes under future climate in the South Pacific. Chapter 7 reports on work undertaken to investigate the distribution of infrastructure in 12 Pacific island countries, with emphasis being on the proportion of built infrastructure in close proximity to the coast and so exposed to coastal climate change impacts. The chapter highlights the very high percentage of infrastructure located very close to the coast and how impacts on such infrastructure could impact on the whole country. Chapter 8 follows the same trend as Chap. 7 but looks at the population distribution across 12 countries in the Pacific. It uses locational data to report on percentage populations in very close proximity to the coastal fringe and how rising sea levels and storm surges related to climate change may impact them. Chapter 9 reports on agriculture under a changing climate in the Pacific. It discusses the significance of agriculture in the Pacific and how climate change and climate extremes may impact on agriculture and sustainability of some agricultural systems. Case studies are used to highlight some of the impacts. Chapter 10 changes from agriculture to marine resources in the Pacific, the importance of such resources to the people and the vulnerability of marine resources to climate change. In Chap. 11, freshwater resources and availability are discussed, including both current issues surrounding freshwater resources and impacts of climate change on water security. Climate change impacts on rainfall and evaporation are also presented. Chapter 12 looks at the impacts of climate change on biodiversity in the Pacific region. It uses the case of terrestrial vertebrate species to show the variety of vulnerable, endangered and critically endangered species that call the Pacific as home and how many of these species occur on one or a few islands only. Many of the species are endemic to the Pacific and so are at an increased risk of extinction due to climate change impacts on the islands they call home. The economic impacts of climate change in the Pacific are explored in Chap. 13. This chapter discusses the economic settings of Pacific islands and how climate change may impact on them. Chapter 14 rounds off the book, looking at the issue of adaptation to climate change. It uses a number of case studies to highlight how different people in different countries of the Pacific are adapting to climate change under different settings. The case studies showcase useful adaptation options and how adaptation could be improved to help people deal with the issues of climate change. So overall, the book covers a wide range of topics very relevant to the climate change debate and to the people of the Pacific and elsewhere.

The travesty is that, quite often, in discourse about climate change and its impacts, the Pacific is overlooked since it is home to only around 12 million people (0.16% of the world's population). What is discounted is that we are talking about 26 countries in this region (13.33% of the 195 countries in the world) having over 30,000 islands, 35 biodiversity hotspots, more than 3200 threatened species of flora and fauna and the world's widest linguistic diversity. The authors contributing to this book hope that it will go some way in highlighting the problems climate change is creating in this part of the world and bringing together a body of literature specifically dealing with the Pacific that will help practitioners make more informed decisions that support them in dealing with climate change.

Finally, I am extremely grateful to all the authors who have volunteered their precious time to share their knowledge with the broader community. I am positive that the knowledge and experience they have willingly shared will have a positive impact on the lives and livelihood of the people of the Pacific. Climate change is now an everyday reality for the Pacific, and their contributions will be appreciated by all.

My heartfelt thanks to the contributors and best wishes to the people of the Pacific in dealing with something they have not contributed to creating but are at the receiving end of probably the greatest impacts. I hope this book serves many researchers and practitioners in this exciting field of climate change.



Armidale, NSW, Australia Lalit Kumar

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AD	Anno Domini
ADB	Asian Development Bank
ANZ	Australia and New Zealand
AOGCMs	Atmosphere-Ocean General Circulation Models
APCC	APEC Climate Centre
APEC	Asia-Pacific Economic Cooperation
APSIM	Agricultural Production Systems Simulator
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
BISP	British Solomon Islands Protectorate
BMI	Body Mass Index
BOM	Bureau of Meteorology
$CaCO_3$	Calcium Carbonate
CBA	Community-Based Adaptation
CDF-t	Cumulative Distribution Function Transform
CePaCT	Centre for Pacific Crops and Trees
CH_4	Methane
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon Dioxide
CO_3^{2-}	Carbonate Ions
CR	Critically Endangered
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cv	Coefficient of Variation
DACCRS	Development Assistance Committee Creditor Reporting System
DSAP	Development of Sustainable Agriculture in the Pacific
DSSAT	Decision Support System for Agrotechnology Transfer
EEZ	Exclusive Economic Zone
EN	Endangered
ENSO	El Niño-Southern Oscillation

ESMs	Earth System Models
ESRI	Environmental Systems Research Institute
EU	European Union
FADs	Fish Aggregation Devices
FAO	Food Agriculture Organizations
FRDP	Framework for Resilient Development in the Pacific
FSM	Federated States of Micronesia
GCCA	Global Climate Change Alliance
GCF	Green Climate Fund
GCMs	Global Climate Models
GDP	Gross Domestic Product
GEIC	Gilbert and Ellice Islands Colony
GERD	Gross Domestic Expenditure
GHGs	Greenhouse Gases
GIS	Geographical Information System
GIZ	German Agency for International Cooperation
GSHHG	Global Self-Consistent, Hierarchical, High-Resolution Geography Database
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome
H_s	Mean Significant Wave Height
ICM	Integrated Coastal Management
ICT	Information and Communication Technology
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
IUCN	International Union for Conservation of Nature
LAT to HAT	Lowest Astronomical Tide to Highest Astronomical Tide
LC	Least Concern
LEAP	Local Early Action Planning and Management Planning
LGM	Last Glacial Maximum
LiDAR	Light Detection and Ranging
LMI	Lifetime Maximum Intensity
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications
MJO	Madden-Julian Oscillation
MORDI	Mainstreaming of Rural Development Innovation
MORDI TT	Mainstreaming of Rural Development and Innovation Tonga Trust
MPAs	Marine Protected Areas
MSL	Mean Sea Level
Mt	Metric Tonnes
N_2O	Nitrous Oxide
NASA	National Aeronautics and Space Administration
NDCs	Nationally Determined Contributions
NESP	National Environmental Science Programme

NGO	Non-government Organisations
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NT	Near-Threatened
OECD-DAC	Organisation for Economic Co-operation and Development's Development Assistance Committee
PACC	Pacific Adaptation to Climate Change
PACCSAP	Pacific-Australia Climate Change Science and Adaptation Planning Programme
PacRIS	Pacific Risk Information System
PCCSP	Pacific Climate Change Science Program
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PDO	Pacific Decadal Oscillation
PICs	Pacific Island Countries
PICTs	Pacific Island Countries and Territories
PLA	Participatory Learning and Action
PNA	Parties to the Nauru Agreement
PNG	Papua New Guinea
PPP	Purchasing Power Parity
PRRP	Pacific Risk Resilience Programme
PSIDS	Pacific Small Island Developing States
PWWA	Pacific Water and Wastes Association
RCMs	Regional Climate Models
RCPs	Representative Concentration Pathways
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RMI	Republic of the Marshall Islands
RO	Reverse Osmosis
SAM	Southern Annular Mode
SEAPODYM	Spatial Ecosystem and Populations Dynamics Model
SLP	Sea-Level Pressure
SLR	Sea-Level Rise
SOI	Southern Oscillation Index
SOPAC	South Pacific Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
SPCZ	South Pacific Convergence Zone
SPCZI	South Pacific Convergence Zone Index
SPEArTC	Southwest Pacific Enhanced Archive for Tropical Cyclones
SST	Sea Surface Temperature
t	Tonnes
TC	Tropical Cyclone
TPI	Tripole Index
UK	United Kingdom
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change

US	United States
US$	US Dollars
USA	United States of America
USAID	United States Agency for International Development
USD	US Dollars
USGS	United States Geological Survey
USP	The University of the South Pacific
VDS	Vessel Day Scheme
VU	Vulnerable
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WDI	World Development Indicators Database
WGS84	World Geodetic System 1984
WHO	World Health Organization
WMO	World Meteorological Organization
WRI	World Resources Institute
WVS	World Vector Shorelines

About the Editor

Lalit Kumar is a Professor in Spatial Modelling, specialising in GIS and remote sensing applications in agriculture, environment and climate change-related impacts. He has an MSc in Environmental Physics from the University of the South Pacific in Fiji and a PhD in Remote Sensing from the University of New South Wales in Sydney, Australia. He worked as a Lecturer at the University of the South Pacific and the University of New South Wales for a number of years before moving to Europe and taking a position as an Associate Professor at the International Institute for Aerospace Survey and Earth Sciences (ITC) where he worked for 5 years. He then moved to the University of New England in Australia where he is currently a Full Professor in Environmental Science.

He has over 25 years' experience in the application of satellite and environmental data layers for broad-scale environmental monitoring, change detection, land-use change and its impacts, above-ground biomass estimation, pasture quality assessment and impacts of climate change on invasive species and biodiversity. He has research and consultancy experience in a number of countries, including Kenya, South Africa, Tanzania, Burkina Faso, Indonesia, India, Nepal, Bhutan, Sri Lanka, Bangladesh, Fiji and Australia, to name a few.

He has published extensively in international peer-reviewed journals, with over 220 journal articles and more than 150 conference papers and technical reports. His work has been cited over 6500 times. He is an Editor on a number of international journals, such as *Remote Sensing*; *ISPRS Journal of Photogrammetry and Remote Sensing*; *Geomatics, Natural Hazards and Risk*; *PLOS One*; *Sustainability*; and *Remote Sensing Applications: Society and Environment.* He has successfully supervised over 25 PhD students to completion and currently has 14 PhD students in his lab group. Some of his work is showcased at lalit-kumar.com, and he can be reached at lkumar@une.edu.au.

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Chapter 9
Agriculture Under a Changing Climate

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9.1 Introduction

Agriculture plays an important role in Pacific Island Countries (PICs) as a source of livelihood and food for communities. Agriculture provides 70–80% of food for people in Papua New Guinea (PNG), Solomon Islands, and Vanuatu; 40–60% of food for Polynesian countries such as Tonga, Samoa, and Cook Islands; and about 30–40% in rural atoll islands in Tuvalu and Kiribati (Bourke 2005; Allen 2015; NMDI 2018; Iese et al. 2018).

The role of agriculture in PICs is diverse, as are the challenges it faces. Agriculture plays a more significant role in higher islands with larger land areas such as PNG, Fiji, Solomon Islands, Vanuatu, Samoa, and Tonga. In these countries, commercial agriculture and involvement of the private sector is more visible and active. The major commercial crops in these countries include taro in Samoa; sugarcane in Fiji; oil palms and coffee in PNG; oil palms, copra, and cocoa in Solomon Islands; kava

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(*Piper methysticum*) and coffee in Vanuatu; and squash, vanilla, watermelons, and root crops in Tonga. There is also higher institutional and functional capacity in these countries in terms of agriculture officers, agriculture-focused NGOs, and development partners' participation in the agriculture sector (Sisifa et al. 2016).

In smaller and low-lying islands (Tuvalu, Kiribati, Cook Islands, Republic of the Marshall Islands (RMI), and Federated States of Micronesia (FSM)), agriculture plays a significant role but mainly for in-country use and semicommercial production. These countries are challenged with limited land areas, poor soils, and large distances between islands (making the islands difficult and expensive to reach and challenging outer-island transportation). Farming in these countries is mainly for household consumption and cultural practices (Sisifa et al. 2016).

About 70% of agricultural systems in the Pacific are rain fed, making them highly vulnerable to variations in rainfall (FAO 2010). Only 2% of the entire 30 million km^2 of the Pacific area is land (Sisifa et al. 2016). Larger Melanesian countries such as PNG, New Caledonia, Solomon Islands, Vanuatu, and Fiji represent about 90% of the land area in the Pacific Islands. The small land area available for agriculture purposes is a major challenge in PICs, especially in low-lying and atoll islands (Sisifa et al. 2016). Most of the good agricultural lands are located near rivers and coastal plains, making them highly exposed to floods and saltwater inundation and intrusion. The atolls and low-lying islands are particularly exposed to coastal flooding and saltwater intrusion and inundation, as most have a highest point at or below 5 m above sea level. Ongoing pressure on land from population growth, urbanization, and infrastructure development reduces the land available for agriculture. The continuous reduction of soil fertility and increasing incidences of pests, diseases, and invasive species also contributes to the vulnerability of Pacific agricultural systems (Sisifa et al. 2016).

The percentage of arable land in different PICs is highly variable. About 30–60% of the land in atolls such as RMI, Tuvalu, and Kiribati is arable land (flat lands that could be plowed). The percentage of arable land looks high, but as the average elevation of these atolls is about 3–5 m above mean sea level, arable lands are highly exposed to sea level rise, saltwater inundation, intrusion, droughts, and salt spray (Sisifa et al. 2016). On the other hand, larger landmasses such as PNG, Solomon Islands, and Fiji have low percentages of arable land, as most land areas have steep slopes and are difficult to cultivate for large-scale agriculture. Agricultural lands in higher islands are vulnerable to heavy rainfall leading to flooding and landslides. Arable lands are mostly located close to coastal areas where they are vulnerable to saltwater inundation and intrusion. Some of the flat lands that would be suitable for agriculture have been taken for developments such as roads, industrial establishments, and residential dwellings (Taylor et al. 2016).

Climate change is seriously impacting the agriculture sector in PICs through increasing the severity of extreme weather events and changing rainfall patterns, sea levels, and increasing average temperatures (IPCC 2019). These changes have had direct impacts on crops and livestock and crucial infrastructure such as roads and outer-island jetties. PICs are committed to reducing the negative impacts of climate change on the agriculture sector. Adaptation actions and risk reduction measures have been employed at different levels to assist farmers to adapt to climate change and climate variability (Iese et al. 2016; McGregor et al. 2016). Many agricultural resilience projects supported by development partners and agencies are building the adaptive capacity of farmers. Farmers are adjusting planting times, shifting to resilient varieties of crops and livestock, improving soil organic matter, adopting agroforestry and low-carbon farming, relocating farms, and integrating climate change and disaster risk management into agriculture policies at national and sub-national levels (Iese et al. 2015, 2016; Taylor et al. 2016; Wairiu et al. 2012).

Despite efforts to reduce the impacts of climate change on agriculture in PICs, the sector will continue to remain threatened by climate change for two reasons. First, climate change-induced hazards such as floods, droughts, and tropical cyclones are expected to increase in severity in the future (IPCC 2019). Sea level and temperatures will also continue to rise. Second, the efforts of PICs to adapt have not been sufficient to prevent damages, resulting in compounding residual impacts that give communities the experience of being in constant "recovery mode." Given the great importance of the agriculture sector for livelihoods, food security, and culture, PICs must transform the sector to be more resilient in the face of the ever-increasing risks associated with climate change.

This chapter provides insights on strategies to transform the agriculture sector to build resilience and productivity in a changing climate. In PICs, the term agriculture is sometimes used to refer to crops, livestock, fisheries, aquaculture, and forestry. This chapter focuses on land-based agriculture, which means crops, livestock, and forestry. We will first provide an overview of the role of agriculture in PICs followed by short summaries of impacts of climate change and climate variability on the agriculture sector. Additional projected future impacts of climate change on crops such as taro, cassava, and potato will be presented based on Pacific-led crop simulation modelling research. Specific case studies are also presented to illustrate key drivers needed to transform agricultural production in PICs. The case studies illustrate systems-oriented approaches that recognize the foundational importance of healthy soils in building the resilience of the agricultural sector. The final part of the chapter provides an overview of key principles that need to be addressed going forward in order to transform Pacific agriculture to be productive and resilient in a changing climate.

9.2 The Role of Agriculture in PICs

Agricultural production in PICs has been growing very slowly over recent decades. Annual production rates grew steadily in the Pacific region since the 1960s but have slowed down since the 1990s in most countries for which there are data (Halavatau 2016). The annual growth rate of the agriculture sector between 2000 and 2008 has varied between countries. Solomon Islands and Cook Islands recorded 4.2 and 3.2% growth, respectively. The growth rate ranges between 1.3 and 1.9% in Vanuatu, Tonga, PNG, and Kiribati. Samoa and Fiji recorded negative growth rates of −0.9

and −2.4%, respectively (Halavatau 2016). There has been a continuous decline in the contribution of agriculture to GDP in PICs. For example, Solomon Islands recorded a decrease in the contribution of agriculture to GDP from 24.2% in 2012 (NMDI 2018) to 16.2% in 2013 (Government of Solomon Islands 2015). Samoa recorded a decline in the contribution of agriculture to GDP from 13.6% in 2006 (Government of Samoa 2016) to 6.4% in 2014 (NMDI 2018). Tonga experienced a decline in the contribution of agriculture to GDP from 26.3% in 2004–2005 to 19.2% in 2009–2010 (Government of Tonga 2016) and 14% in 2015 (NMDI 2018). Fiji also recorded a decrease in the contribution of agriculture to GDP from 16% in 1990 to 10.4% in 2014 (Ministry of Agriculture 2014; NMDI 2018). The declining growth rate of production is due to loss of soil fertility, increases in pests and diseases, demographic changes, and the impacts of climate change and climate variability. The declining contribution of agriculture to GDP is due to the declining growth rate in production, as well as changes in trade agreements, price fluctuations due to the vagaries of markets, and reliance on a few export crops. The growing contribution to GDP of other sectors, such as tourism, may also be a factor in some countries.

9.2.1 Significance in GDP

Despite its decline, agriculture is still a critically important economic and livelihood sector in PICs (Halavatau 2016). Larger PICs, especially in Melanesia, have a higher contribution from agriculture to GDP as shown in Table 9.1. PNG had a contribution from agriculture, forestry, and fisheries to GDP of 18.8% in 2014. Vanuatu and Solomon Islands have agriculture sectors that contribute 24.4 and 24.2% of GDP, respectively, in 2012. Most of the agriculture contributions in the three mentioned countries come from export of commodities such as copra, palm oil, cocoa, kava, and coffee. Tonga recorded a 14% agriculture contribution to GDP in 2015, while Samoa recorded 6.4% in 2014 and Fiji recorded 10.4% agriculture contribution in 2013. Most of the contribution of agriculture to GDP is attributed to exports of fish, root crops, kava, fruits, coconut products, and sugar (only for Fiji).

The contribution of agriculture to GDP in smaller PICs including atolls varies widely. The FSM recorded a 14.5% contribution in 2013. FSM's main export products are betel nut, kava, some cooked root crops, bananas, and vegetables. Kiribati's agriculture sector contributed 25.6% to GDP in 2011. Copra is the main export product from Kiribati. Tuvalu (11.4% in 2011) and Niue (17.4% in 2012) do not export agriculture products, but agriculture contributes enormously to local food consumption and provides other social-economic benefits. The agriculture sectors in Cook Islands (2.1% in 2012), Nauru (1.2% in 2004), and Palau (1.4% in 2014) have small contributions to GDP, but agriculture plays an important role in food and domestic markets and social activities.

Table 9.1 Summary of the role of agriculture in PICs

Country	Agricultural trade		Total land area (2003) (ha)	% of arable and perm. cropland	% of household income from agriculture	% of labor force engaged in agriculture and forestry	% of GDP from agriculture
	% of total exported	% of total imported					
Fiji	15.8 (2013)	9.1 (2013)	1,827,000	13.7 (2009)	15.8 (2008)	16.9 (2008)	10.4 (2013)
Papua New Guinea	19.2 (2013)	2.2 (2013)	45,286,000	2.6 (2012)	72.4 (2005)	10.8 (2010)	18.8 (2014)[a]
Solomon Islands	60 (2013)	14.1 (2013)	2,799,000	3.8 (2012)	42 (2006)	51.7 (2013)	24.2 (2012)
Vanuatu	74 (2014)	11 (2014)	1,219,000	41 (2007)	28 (2012)	53.2 (2009)	24.4 (2013)
Samoa	5.5 (2013)	19.9 (2013)	283,000	13 (2009)	19.5 (2008)	33 (2011)	6.4 (2014)
Tonga	44.4 (2014)	19.4 (2014)	72,000	41.3 (2011)	23.4 (2014)	23 (2016)	14 (2015)
Cook Islands	0.1 (2013)	12.8 (2012)	24,000	1.6 (2009)	8.3 (2011)	2.2 (2011)	2.1 (2012)
Tuvalu	0.1 (2013)	3.1 (2013)	3000	60 (2012)	15.2 (2016)	16.9 (2016)	11.4 (2011)
FSM	14.7 (2013)	15.1 (2013)	70,000	31.4 (2012)	19.2 (2013)	16.2 (2013)	14.5 (2013)
Kiribati	54.1 (2012)	18.9 (2012)	73,000	42 (2012)	37.8 (2006)	9.1 (2015)	25.6 (2011)
RMI	1.2 (2014)	0.2 (2014)	18,000	64 (2013)	Fisheries employed 10% of population	0.3 (2006)	In 2012, Fisheries contributed 1.2% to GDP (Republic of the Marshall Islands 2013)
Nauru	0 (2013)	6.2 (2013)	2000	4 square km	3.9 (2013)	4.8 (2011)	1.2 (2004)
Palau	0.3 (2013)	9.1 (2013)	46,000	10.9 (2012)	2.5 (2006)	9.8 (2015)	1.4 (2014)
Niue	2.9 (2013)	10.5 (2013)	26,000	19.2 (2009)	7.1 (2016)	10 (2016)	17.4 (2012)

The data have been compiled from NMDI (2018), FAO (2018a, b), Republic of the Marshall Islands (2013), and Government of Nauru (2005)

[a]PNG National Statistics Office. https://www.nso.gov.pg/images/NationalAccounts2007-2014.pdf

9.2.2 Significance of Agriculture at the Household Level

The most important role of agriculture is providing food and sustaining incomes for households especially in rural areas in PICs. The percentage of households that name agriculture as the main source of income varies widely between countries. For example, in Palau and Nauru, agriculture is the main source of income for just 3% of households, whereas in PNG 75% of households rely on agriculture as the primary source of income (see Table 9.1). In terms of labor force employment, the agriculture and forestry sector employs about 17% in Fiji, 50% in Vanuatu and Solomon Islands, 23% in Tonga, and 33% in Samoa (NMDI 2018).

Indicators for measuring the contribution of agriculture in PICs tend to focus on production aspects that underestimate the crucial role of the sector. In reality, most people in PICs are involved in agriculture in one form or another, either as producers or consumers. In Solomon Islands, PNG, and Vanuatu, 80% of the population is involved in subsistence farming and depends entirely on subsistence production for daily sustenance (this is almost the entire rural population of these countries) (Government of Solomon Islands 2015; Government of Vanuatu 2015b; Independent State of PNG Ministry of Agriculture 2007). In Vanuatu, the people living in urban areas (about 20% of the population) also rely on agricultural products bought from local markets for food and cultural activities. In Niue, about 87% of households are actively involved in agriculture (Department of Agriculture, Forestry and Fisheries 2015). Around 65% of Tonga's population live in rural areas and are dependent on agriculture and fisheries as their main source of livelihood (Government of Tonga 2016). In 2011, about 67.5% of the population of Cook Islands were subsistence farmers who relied mostly on agriculture for daily sustenance (Government of Cook Islands 2015). In Nauru, a country with no agriculture exports and with very limited arable land for agriculture, 70% of the average diet is sourced from locally produced food (Government of Nauru 2005).

9.2.3 Significance of Agriculture for Social Cultural Activities

Agriculture is an important sector for sustaining culture and maintaining social bonds and practices in PICs. Most of the items needed for cultural exchange and practices are from agricultural products (Barnett 2011). The welcoming ceremonies in Samoa and in Fiji are practiced with kava. High-value cultural items are exchanged during weddings, funerals, ceremonies for forgiveness, and marriage proposals. These items are raw and processed agriculture products such as fine mats, tapa, root crops, pigs, betel nuts, and handicrafts (Allen 2015; Ministry of Agriculture 2014). For example, in the Federated States of Micronesia, yams, sakau (kava), breadfruit, taro, and pigs are crucial for ceremonies and gifting to cement culture and social bonds (FSM Department of Resources and Development 2012). Subsistence and household gardens allow the participation of everyone in the family where men, women, and children work together.

9.2.4 Resourcing Agriculture

The limited budget allocated for the agriculture sector by national governments is one of the major constraints in developing and building the resilience of agriculture in PICs. Although agriculture is considered to be a very important livelihood and economic sector, the annual budget allocations are small. For example, as reported by the Solomon Islands Agriculture and Livestock Sector Policy 2015–2019, the budget for the agriculture department is less than 2% of the national budget, which does not reflect the importance of agriculture in the national economy. The policy states that this lack of resourcing is a "major constraint" to providing essential services to rural populations (Government of Solomon Islands 2015). Samoa's annual budget for the agriculture sector was only 2.4% of the national budget in 2015–2016 (NMDI 2018). The government emphasized the need for development partners and the private sector to contribute toward implementing the Samoa Agriculture Sector Plan 2016–2020 (Government of Samoa 2016). The atoll nation of Tuvalu allocated an average of about 0.3% of the national budget to the Ministry of Natural Resources between 2012 and 2014, and agriculture received only about 2.6% of the limited allocation to the ministry (Government of Tuvalu 2016). In many PICs, the largest expense for most ministries is salaries. For example, in Tonga the Ministry of Agriculture, Forestry, Food and Fisheries (MAFFF) uses about 60–70% of their budget allocation for salaries and 30% on operational costs such as fuel, electricity bills, and others (Government of Tonga 2016). The limited national budget allocation to the agriculture sectors of PICs restricts the provision of services to farmers in urban and rural areas.

The government agriculture departments rely on projects funded by donors and contributions from the private sector to supplement the services and enhance coverage of services. Donor funds also provide support for agricultural research and other technologies needed to improve productivity. As highlighted by Fig. 9.1, Pacific Island Countries have been receiving an average of USD 67.6 million per year between 2007 and 2016 in official development assistance for the agriculture sector. Assistance for agriculture increased between 2007 and 2011 but decreased from 2012 to 2016. Overall, there was a slight decline over the 10 years from 2007 to 2016 (OECD 2018a).

Bilateral commitments in support of the Rio markers (biodiversity, climate change mitigation, climate change adaptation, and desertification) are tagged in the Development Assistance Committee (DAC) Creditor Reporting System (CRS) database. This data shows that aid activities targeting climate change adaptation in the agriculture sector have fluctuated from year to year but have increased slightly

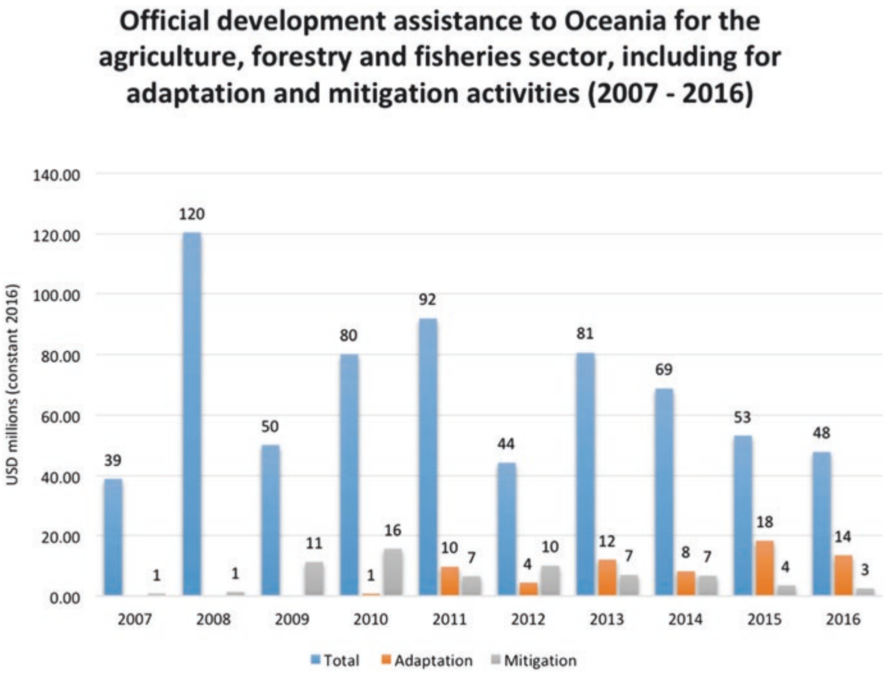

Fig. 9.1 Total development assistance for the agriculture sector in PICs (Oceania) between 2007 and 2016. Note: to avoid double counting, mitigation and adaptation activities should not be added together. Adaptation and mitigation funds are part of the overall development assistance for the agriculture sector. Assistance is from OECD countries so China is not included in this analysis. (Source: OECD 2018a, b)

between 2009 and 2016. On the other hand, bilateral commitments for activities targeting mitigation in the agriculture sector increased rapidly between 2008 and 2010 and have steadily decreased since then. It is important to note that in the OECD-DAC database the same activity can be marked for multiple environmental objectives (e.g., both adaptation and mitigation) so adding up the adaptation-related finance and mitigation-related finance could result in double counting. Bilateral commitments for adaptation and mitigation represent a potentially overlapping subset of total bilateral commitments to the agriculture sector (OECD 2018b).

The Green Climate Fund (GCF) and other multilateral climate funds are also providing assistance for adaptation and mitigation in PICs. Unfortunately, out of the eight countries with approved projects by the GCF, only Vanuatu's project will provide benefits to the agriculture sector. Vanuatu's project will focus on improving climate services, which will assist farmers to prepare to reduce the risks induced by climate hazards. Vanuatu has also been benefiting from a GCF readiness program on Reducing Emissions from Deforestation and Forest Degradation (REDD+) (GCF 2018).

9.3 Impacts of Extreme Events and Rising Sea Levels on Agriculture

Agricultural production in PICs is very vulnerable to the negative impacts of climate hazards. Both sudden-onset climatic hazards such as tropical cyclones, droughts, floods, and storm surges and slow-onset hazards such as sea level rise and rising average temperature are affecting the agriculture sector in PICs. This section provides a brief summary of the impacts of climate change on the agriculture sector in PICs, according to large-scale post-disaster needs assessments and other research. More details on the impacts of climate change on agriculture in PICs can be found in Taylor et al. (2016), Barnett (2011), Iese et al. (2015), Bourke (1999), Allen and Bourke (2001), Wairiu et al. (2012), Iese et al. (2016), and McGregor et al. (2016).

9.3.1 Observed Impacts of Climate Change and Climate Variability on Agriculture

Climate change is impacting agricultural production in PICs through slow-onset stressors such as rising average temperatures, shifting rainfall patterns, and sea level rise. At the same time, agricultural production is being impacted by the influence of climate change in increasing the frequency and/or severity of extreme weather events. There is a greater understanding of the agricultural losses and damages caused by extreme weather events compared to those caused by slow-onset events. This is because the costs of extreme weather events have been quantified fairly precisely by post-disaster needs assessments. Tropical Cyclone (TC) Evan in 2012 caused WST 62 million (USD[1] 23.8 million) in losses and damages to the agriculture sector in Samoa and FJD 37.7 million (USD (see Footnote 1) 11.7 million) in Fiji (Government of Samoa 2013; Government of Fiji 2013). TC Pam, a Category 5 cyclone, devastated Vanuatu in 2015 and caused losses and damages to the agriculture sector valued at USD 56.5 million (Government of Vanuatu 2015a). TC Pam also generated waves that caused severe damages to food sources, water and infrastructure in Tuvalu and Kiribati. The waves and strong winds destroyed about 30–90% of crops on many islands of Tuvalu. The economic impacts of TC Pam were estimated to be 25% of Tuvalu's projected GDP in 2015 (Katea 2016). Severe Tropical Cyclone Winston in 2016 incurred losses and damages on the agriculture sector valued at FJD 542 million (USD (see Footnote 1) 254.7 million) (Government of Fiji 2016). TC Gita, which affected the agriculture sector in Tonga in 2018, resulted in losses and damages valued at TOP 97.5 million (USD (see Footnote 1) 42.8 million) (Government of Tonga 2018). Flooding in Honiara, Solomon Islands, in 2014 affected over 9000 households in Guadalcanal Island, destroying more than

[1] https://www.xe.com/currencyconverter/. Accessed 25 Mar 2019.

75% of household food gardens in these areas. The total loss and damage to agriculture from the flooding in Honiara was an estimated USD 18 million (Reliefweb 2018). In the RMI, a 16% fall in copra production occurred in 1996 due to heavy rainfall during an El Niño year (Republic of Marshall Islands 2013). According to a group of farmers in Ranadivi, Tavua in Fiji, the ongoing 2018 drought caused a loss of sugarcane (Fiji Times 2018). Farmers have not been able to cultivate the land for the following year's planting season as the soil has been too dry to plow.

Shifts in the normal rainfall patterns have also been affecting local farmers in PICs. A crop modelling simulation on impacts of rainfall on taro production in Santa Isabel, Solomon Islands, revealed that the likely cause for losses in taro yield was nitrogen stress caused by an increase in daily rainfall on Santa Isabel in 2011, leading to increased runoff. The steepness of the slopes where taro is cultivated, combined with the practice of removing all weeds and leaving no ground cover, has also contributed to this impact (as some farmers believe that a clean farm with exposed soil is a sign of a hardworking farmer) (Quity 2012). In Nabukelevu, Serua province in Fiji, rainfall has increased compared to the past 20 years according to the villagers, causing a loss of cash crops. Mandarin trees, which are the main source of income in the community, are not fruiting anymore, and duruka (Fiji asparagus) is not budding, causing a loss of income and a sudden change in sources of livelihood in the villages. The villagers are now spending more time hunting wild pigs than gathering wild fruits for food and income (UNESCO 2017).

Rising sea levels and storm surges causing saltwater inundation, intrusion and salt spray are affecting coastal agricultural production, especially in atolls and low-lying areas in PICs. Sea level rise in combination with other climate hazards decreases the availability of fresh groundwater for agriculture. Most groundwater in Pacific Islands exists beneath the surface of mostly limestone permeable islands as freshwater lenses. Sea level rise will eventually lead to a reduction in freshwater in Pacific Islands, especially on atolls and along the coastal areas of larger islands as freshwater lenses are contaminated by salinity intrusion from below or inundation from above. Freshwater is being contaminated as salinity intrusion is causing a reduction in freshwater. Water salinity as well as soil salinity in atolls and along coastal areas will increase with the rise in sea levels. For example, assessments conducted in 2009 of wells in the outer islands in Chuuk State in the Federated States of Micronesia found, in most cases, that well water had increased in salinity since 1984 (Shigetani 2009). On Tarawa, Kiribati, it has been found that by 2050 rainfall could decline by 10% and sea levels could rise by 0.4 m, shrinking the thickness of the freshwater lens by as much as 38% (The World Bank 2000). In Funafuti, Tuvalu, salinization of the groundwater lens due to sea level rise has impacted giant swamp taro production, worsening prior salinization of the water lens caused by the construction of the Funafuti airstrip (Lewis 1989). Freshwater lens observation in Laura, Majuro in the Marshall Islands showed that the 1998 up-coning of the freshwater lens as a result of a long drought still exists and has changed little in shape (Koda et al. 2017). Interestingly, the results indicated that saltwater intrusion did not affect crops despite the increase in groundwater withdrawals. Studies in Tonga showed increasing salinity of wells located on the low-lying coastal areas because of saltwater intrusion (Government of Tonga 2012). Groundwater reserves in the northwest of Savai'i, Samoa, are becoming more saline due to saltwater intrusion, resulting in the abandonment of some boreholes (Berthe et al. 2014). Increased salinity of groundwater is influenced by factors such as sea level rise resulting in seawater intrusion (from below) or inundation (from above), rising temperatures resulting in higher evaporation rates, and decreased rainfall.

The impacts of salinity on soil and crops have been observed by farmers especially in low-lying islands. Saltwater intrusion into inland gardens (primarily for taro production) has already begun to affect some atoll islands of Solomon Islands like Ontong Java, making tubers yellow and bitter and unsuitable for consumption (Maeke 2013). Furthermore, increases in salinity are reportedly impacting the growth of giant swamp taro in Tuvalu (Tekinene 2014). Saltwater intrusion during strong westerly winds and rough spring tides destroyed giant swamp taro pits in Funafuti, Tuvalu. On Nanumaga Island, the giant swamp taro pit on the northern part of the island is frequently flooded during high tides, affecting the growth and reducing the yield. Impacts of salinity on crops are more visible during droughts as was observed in the La Niña event of 2011 (Tekinene 2014). In Nataleira village in Fiji, farmers stopped planting rice at the lowland areas because of saline soils from saltwater inundation during storm surges. Loss of yield due to the salinization of groundwater and soils is expected to continue to affect food security and income security, increasing hardship and poverty in Pacific households (UNESCO 2017).

9.3.2 Future Impacts of Climate Change on Crops in PICs

Studies investigating the future impacts of climate change on agricultural crops in the Pacific are limited. Nevertheless, a small number of researchers have begun to explore this topic by applying crop models to explore future projections for specific sites and crop varieties. Unfortunately, the results of crop models have to date remained within the domain of researchers and have not been widely adopted by policy-makers to inform agricultural adaptation and mitigation strategies.

The impacts of climate change on future taro production in the Solomon Islands were investigated by applying the Decision Support System for Agrotechnology Transfer (DSSAT version 4.5) model package. Maeke (2013) simulated the yield of *Tango Sua*, a cultivar of Taro (*Colocasia esculenta*), using the soil profile from Bellona Island, historical daily weather data from Honiara, and future climate change projections for Solomon Islands. The future climate change projections came from Pacific Climate Futures version 2.0, a web-based tool built upon extensive analysis of global models from climate change in the Pacific, produced by the Pacific Climate Change Science Program in 2011. Projected changes in temperature and rainfall were considered, based on 20-year time periods around 2030, 2055, and 2090. By 2030, temperature is projected to increase by 1 °C and annual rainfall is projected to increase by 8%, leading to a simulated reduction in yield of between 13.1 and 23.2%. Temperature and rainfall are both projected to continue to increase to 2090, leading to further reductions in simulated yield of up to 36% by 2055 and up to 57.7% by 2090. The projected yield reductions are likely due to nitrogen leaching from runoff associated with excess rainfall. The most vulnerable site in Bellona Island is Sa'aiho which has the highest projected yield reduction due to its limited soil fertility and loosely packed soil structure that is susceptible to leaching. When future carbon dioxide concentrations are added to the simulations, the projected yield for *Tango Sua* still declined for two sites by 2030 by between 2.8 and 5.9% (but by a lesser degree than for simulations that only considered temperature and rainfall). Simulations showed an increase in yields of between 0.5 and 1.4% by 2055 and 4.6 and 6.7% by 2090. However, for Sa'aiho (a site with poor soils), yields continued to decline by 12.5%, 10.5%, and 12%, respectively, in 2030, 2055, and 2090. The major variables contributing to this change in projected yield are soil type and quality, increase of temperature and rainfall, as well as carbon dioxide fertilization. There is more work needed to validate DSSAT taro model in PICs.

The decline in taro yield under projected changes in rainfall and temperature for 2030, 2055, and 2090 is also in line with decline in yield of taro varieties such as *Tausala-Samoa* and *Lehua* varieties simulated for high volcanic island (Santa Isabel) in Solomon Islands (Quity 2012).

Nand (2013) simulated the impacts of El Niño Southern Oscillation (ENSO) and future climate scenarios on future yields of the *Desiree* potato variety in Rakiraki and Koronivia in Fiji. Simulations showed that during seven El Niño years (between 1960 and 2012), the average yield in Rakiraki declined between 30 and 60%, while the average yield in Koronivia increased by 31%. The varying yield responses at each site were due to the effect of El Niño on the amount of rainfall received. The western side of Viti Levu (Rakiraki) received below normal rainfall during El Niño years. On the other hand Koronivia, which is located on the windward side of Viti Levu Island, received a fairly normal amount of rainfall during El Niño years (Nand et al. 2016). When simulating future climate change using the Pacific Climate Futures for Fiji, the *Desiree* variety produced zero yield in 2055 for Rakiraki site only and in 2099 for both Rakiraki and Koronivia sites. The increase of temperature and rainfall variability are the two main variables that affect the simulated future yield of the *Desiree* variety. The *Desiree* variety is sensitive to slight increases of temperature as it reduces tuber formation (Nand 2013). The use of crop models to assess the impacts of climate change on crops revealed that the impacts are very specific depending on the type of variety, crop, and soil or location of the farm.

The impacts of future climate change projections were also simulated on cassava varieties in Fiji (branching and non-branching) using the Agricultural Production Systems Simulator (APSIM) model. Cassava yields were projected to decline by up to 9% by 2030 and up to 18% by 2050. In addition to declines in yield, the year-to-year variability was shown to increase by up to 19% by 2030 and up to 28% by 2050 (the increase in variability is driven by more frequent lower yielding years) (McGregor et al. 2016). According to Crimp et al. (2012), the severity of impacts on cassava yields depends mainly on soil types and soil characteristics at different locations.

9.4 Case Studies: Reducing the Impacts of Climate Change on Agriculture

Pacific Island Countries have been working hard in adapting and coping to reduce the impacts of climate change on agriculture. Most national and community-based adaptation initiatives for the agriculture sector are donor-funded projects implemented by national governments, regional organizations, NGOs, private sector actors, and farmers. However, most approaches to date have not taken a systems-oriented approach and have treated components of the agriculture system separately. For instance, projects have supported vulnerability assessments, the introduction of new early maturing crop varieties and resilient varieties of crops and livestock, farm diversification and agroforestry, and reducing the risks of flood hazards through developing drainage systems and floodgates. While many of these activities have been useful in reducing vulnerability, more can be done to take a systems-oriented approach, recognizing the health of soil as the foundation of resilience. This section presents selected case studies that illustrate useful approaches that—if adopted more widely—could support the transformation of the agriculture sector in Pacific Island Countries. Adopting a holistic, systems-oriented approach is crucial to building the resilience of the agriculture sector. Addressing the health of soil is fundamental and is a key aspect of the system that is typically neglected in vulnerability assessments. Each of the case study illustrates how building the resilience of the agriculture sector to climate change starts with the soil. The first example is a policy case study (of the Tonga Agriculture Sector Plan—TASP) that shows how systems-oriented approaches to resilience that focus on household food security and improving the health of the soil first can be effectively embedded into the overarching plan for the agriculture sector as a whole. The second case study illustrates the benefits of broadening beyond the usual household and community vulnerability assessments to instead consider the water catchment as a whole, considering land use, landforms, biodiversity, water, and agricultural practices. The last three case studies focus on improving soil health over the long term using organic sources such as compost, mucuna, and seaweed fertilizer. The case study on the atoll islands looks at how to increase agricultural resilience on a small landmass and with poor soils and limited water using a combination of applied research on soils, crop diversification, and technologies to increase water use efficiency.

9.4.1 Tonga Agriculture Sector Plan for a Resilient and Sustainable Agriculture System

A good example of a country's leadership to improve agricultural production in a changing climate is the Tonga Agriculture Sector Plan (TASP) 2016–2020. Agriculture is very important for Tonga as 75% of the population live in rural areas and depend predominantly on agriculture and fisheries for their livelihoods.

Although only 10% of farmers are categorized as commercial farmers, the contribution of the agriculture sector to GDP has averaged around 20% in the last 10 years. Climate change and natural hazards have severely impacted the agriculture sector in Tonga in the past, and the country has consistently been in the top three most risk-prone countries in the world from natural hazards (climate and non-climate hazards), according to the World Risk Index (United Nations University 2014, 2016; Government of Tonga 2016).

Given this, it is understandable that the TASP places heavy emphasis on climate change adaptation and resilient agriculture. Climate change is integrated in all aspects of the sector plan. The term "climate change" is mentioned 72 times, while "climate" is mentioned 141 times in the plan. The TASP states:

> Future agricultural development initiatives will need to heed the importance of including climate change adaptation (CCA) and disaster risk reduction (DRR) into programmes and projects that target the sector. The best way to achieve this is to focus on building resilience, with traditional production systems forming a strong foundation. (Government of Tonga 2016)

Two of the TASP's four strategic objectives are particularly relevant to building resilience to climate change. These are "to develop a climate-resilient environment" and "to develop diverse, climate-resilient farming systems for the Kingdom's islands." The TASP also has three specific objectives (for the whole plan), which are to (1) develop baseline knowledge for sustainable management of soil and water (for agriculture), (2) develop climate-resilient guidelines and indicators for diverse farming systems, and (3) build capacity for climate-resilient agriculture (diverse farming systems and adaptive communities).

Activities under the TASP include upgrading and equipping soil laboratories, upgrading soil profiles, conducting a national soil survey, and updating national soil maps. These outputs will facilitate improved understanding among Tongan farmers of organic matter and soil carbon content as well as soil nutrient availability and how current farming practices and changing climate parameters affect these. From these activities, it is hoped that knowledge will be generated on ideal combinations of organic fertilizers and green manures for improving soil health, increasing soil water retention capacity, and sustaining crop yield with minimum impacts on environment.

Another important activity in the TASP is to improve meteorological information and data availability for agriculture. This is being achieved through a partnership project between the Tongan Government and the APEC Climate Center (APCC), from South Korea. From this partnership, soil-moisture balance maps will be developed that link relevant soil parameters from soil profile data (in particular available water-holding capacity) with relevant meteorological data such as derived potential evapotranspiration (PET). These maps will highlight areas with moisture deficits and drought risks. Also proposed is the further development and refinement of crop models, which can be linked to current and future analyses of climate risks and adaptation options. Targeted research will also be undertaken to support improved agrometeorological advice for decision-making. Climate forecasts and potential impacts have been translated into the Tongan language and made available on the Tonga Meteorological Division's website.

The TASP focuses on a "systems approach" to agriculture rather than a crop-based approach. In a changing climate, where multiple variables are changing simultaneously, viewing agriculture from a systems-oriented perspective is more likely to ensure resilience. The systems approach is centered on soil health and water availability and how farming management techniques, climate parameters, and other biological and human impacts affect the balance of the system.

The TASP is focused on the creation of knowledge and usable information about the current status of the system and how climate change will impact the system going forward. This has included the development of decision support tools such as crop models and maps (using Geographic Information Systems) to frame information so that it can be used to inform decision-making for resilient agriculture. In addition, the TASP has facilitated the transfer of information between different stakeholders through active and participatory research projects at research stations and farmer field schools.

The TASP has a community-focused approach founded on improving food security for communities before commercialization of products. This is based on the "community readiness" approach that is at the heart of the community planning processes led by the Ministry of Internal Affairs, the NGO Mainstreaming of Rural Development Innovation Tonga Trust (MORDI TT), and funded by the International Fund for Agriculture Development (IFAD). The community readiness approach focuses on empowering communities to take control of their own development process through building community capacity and transforming the surrounding enabling environment (through developing new markets and giving communities the skills to find funding to develop critical infrastructure).

The TASP was funded by multiple donors with interests in agricultural development, climate risk resilience, and sustainable livelihoods of communities. There is a very clear call in the TASP for NGOs and the private sector to support the upscaling of agricultural research and advisory services to extend their reach to every farmer and community in Tonga.

9.4.2 USAID Food Security Adaptation Project: Sabeto District, Nadi, Fiji Islands[2]

The food security project *"Enhanced Climate Change Resilience of Food Production Systems for Selected PICTs (Fiji, Kiribati, Samoa, Solomon Islands, Tonga, and Vanuatu)"* used a holistic assessment approach to develop a plan for increasing resilience of food systems. The Pacific Community (SPC) implemented the

[2] This case study was summarized from a field assessment report "Community based climate change vulnerability assessment of the Sabeto Catchment" by SPC (2013).

USAID-funded project in all six countries. In Fiji, the Sabeto District at Nadi, Viti Levu, was chosen as the project site. The Sabeto catchment covers 13,819 ha and is located halfway between Nadi and Lautoka. Almost 96% of the catchment is native land and 4% is freehold land. Landowners' consultation is vital before any development takes place in the catchment. Four villages from the Sabeto District were selected, namely, Korobebe, Nagado, Naboutini, and Nakorokoroyawa. The intervention was in two parts: (1) the analysis of the vulnerability of food and agriculture systems in the villages and (2) implementing agriculture interventions to improve food production, food security, and livelihoods in the villages.

Three different community-based methods were used to assess the vulnerability of the agriculture systems in the villages. These methods were land use surveys, participatory rural appraisal (hazard mapping, climate change impact mapping), and household income and expenditures surveys aimed at assessing the sensitivity and coping capacity of the communities.

The land use survey was conducted by the Government of Fiji's Ministry of Primary Industry and the Land Resources Division within SPC. The survey provided a description of land resources, soil types and structures, land availability, limitations, and potential uses. This was done through collection and preparation of soil maps and land use capability maps for the Sabeto catchment area. Satellite images (1:10,000) were used to identify land use types. The assessment also covered food sources and consumption patterns of villagers. The information collected was used to determine the vulnerability of the selected communities as well as their agricultural production environment. Field findings were integrated into GIS, and maps were drawn to show soil types, land use, land capability, and boundaries.

As part of the participatory rural appraisal, SPC developed their own methodology to assess the vulnerability of food security systems at the community level. The climate change vulnerability assessments found that the vulnerability index (out of 5) for all four communities ranges from high (3.75) to very high (4.35). A food availability assessment found that communities' reliance on processed foods is high, ranging from 51 to 54.4% or carbohydrates and 56.4–66.8% for proteins. The high reliance on imported and processed foods increases food insecurity, as these foods are expensive relative to household incomes and prices of imported and processed foods are volatile, as they are influenced by international markets. This detracts from the ability of households to pay for essential costs such as education, health, and building resilient houses. Overall, the assessment of soil, land use, land capability, food security, and climate change vulnerability showed a need to devise adaptation measures to reduce impacts of climate change on villages' food systems.

Agricultural adaptation measures were put in place to diversify agriculture systems, improve soil fertility, and ultimately increase the resilience of food security and livelihoods at all villages. Crop nurseries were established in all villages to raise and multiply climate-resilient crops and trees before distributing to farmers. The crop nurseries included traditional crops and varieties, such as wild yams, cultivars that are commonly planted in the area, and varieties from the climate-resilient collection from the Centre for Pacific Crops and Trees (CePaCT) at the Pacific Community. The climate-resilient collection included taro, cassava, and drought-tolerant, yellow-fleshed sweet potato varieties, which are rich in pro-vitamin A. Resilient crops were distributed to farmers for field evaluation, with the aim of increasing the stability of production during droughts, floods, and cyclones. Demonstration farms were also established to show the use of mucuna bean (*Mucuna pruriens*) in maintaining and improving soil fertility and how contour farming on slopes can expand farming areas. Piggery and chicken demonstration farms were established around the villages to encourage farmers to raise their own livestock to improve protein sources and reduce reliance on purchased foods. Women's groups were also trained in beekeeping and honey production as an additional source of income.

This case study is unique because of the approach used to assess the vulnerability of agriculture and food security for the communities. The team used an integrated vulnerability method where scientific and technological analysis of soil types, land use, and land availabilities was combined with participatory methods through community consultation. Through the participatory methods, the communities mapped their risk areas (in relation to the impacts of hazards), ranked the impacts and vulnerability, and discussed solutions to adapt the agriculture system in each village. The spatial scale of the assessment covered the whole catchment rather than village boundaries and encompassed the whole agriculture system including land, water, crops, livestock, and sociocultural factors.

9.4.3 Improving Soil Health and Land Availability: Atolls and High Islands

Soil is the foundation of crop production, and as such, the health of soil is very important for the resilience of agriculture systems. Crops grow more vigorously when all the important plant nutrients are available for plant growth; yield increases, and crops are more tolerant to climate-influenced hazards such as droughts, sea level rise, and pests and diseases. Most large-scale, commercial farmers and agriculture departments in Pacific Island Countries use chemical fertilizers to "speed up" the growth of crops. Unfortunately, the long-term use of chemical fertilizers changes the biological composition of soil (making it more acidic), and excess nutrient runoff has detrimental impacts on waterways and oceans. Despite this, few research and adaptation projects have focused on improving soil health through techniques such as organic composting, green manure, and diversification of crops.

Atoll Soil Health Project

The project "*Improving soil health, agricultural productivity and food security on atolls"* focused on the development of sustainable soil health technologies for atolls in order to improve production of staple root crops and nutritious crops. The project was funded by the Australian Centre for International Agricultural Research (ACIAR) and was implemented in partnership with the Government of Kiribati, the Government of Tuvalu, the Government of Marshall Islands, the Pacific Community (SPC), and many universities in Australia (ACIAR 2018).

In Kiribati, one cassava variety, six varieties of sweet potato, and three varieties of taro were collected from farmers in Kiribati (from the atolls of Abemama and Butaritari and Banaba Island) and evaluated in the atoll of Tabiteuea North. The taro varieties were evaluated against three introduced varieties from the CePaCT climate-ready collection. The evaluation revealed that yields of sweet potato are better when compost is applied in the subsoil and planting materials are inserted into flat soil which is mounded after a few weeks. In Tuvalu, the evaluation revealed that certain varieties of sweet potato performed better than others (e.g., the PNG variety performed better than Banaba and PRAP varieties). The better-performing varieties were distributed to outer islands to help communities recover after Tropical Cyclone Pam.

The project also developed a participatory productivity index in each country based on seven factors. The factors were (1) income ($/week and percentage to buy food), (2) decision-making on land use, (3) farming skills (farmers, agriculture department), (4) farm productivity of current production, (5) farm resilience (above and below ground), (6) quality of land (from participatory method and soil test), and (7) greenhouse gas emission reduction (biodiversity and soil carbon). After the assessments, spider-web diagrams were drawn to show the relationships between each of the factors and production. Farming skills and household incomes were consistently the most limiting factors for increasing production. The next most limiting factors were lack of farm resilience and low productivity of current production. The spider-web diagrams display baseline information for communities, against which progress can be measured both during and after the completion of the project.

Soil testing was also conducted in Kiribati, Tuvalu, and the Marshall Islands using the "*Palintest SKW 500 Quick Soil Test Kit.*" It was found that most test sites had limited potassium and all had limited iron, copper, and manganese. The project also analyzed more than 100 soil and compost samples from Kiribati, Tuvalu, and the Marshall Islands. The analysis consistently showed high pH and very low levels of potassium and manganese. Even in improved soils (that had had additions of compost), levels of potassium and manganese were found to be only marginal to adequate. The analysis showed low levels of copper and iron in some of the soils, but levels of available and total potassium and available zinc were surprisingly adequate to good. Nutrient omission trials have been discussed to determine whether soil tests are accurately predicting potassium levels for high pH sandy soils. Recipes for improved compost were created using different combinations of manure, ash, sea cucumber, and green leaves. The application of compost did not improve each nutrient significantly, but the combined effect of small increases in multiple nutrients significantly improved growth and yield.

The use of irrigation was also trialled in the field during this project. Initially, field assistants manually irrigated crops using buckets, but water was not reaching the rooting zone of plants. The water issue was resolved when a well was dug and

Fig. 9.2 Terraced pits with "rooms" for different crops such as giant swamp taro, sweet potato, and taro

water was pumped to an overhead water tank, providing a consistent source of gravity-fed water for irrigation. Soil water meters were also installed to gauge how much water should be applied and detect water distribution in the soil. Using water meters to fine-tune how much water should be applied proved effective in conserving water while ensuring plants received enough to thrive. This tool could be applied on other atolls, where water is generally a limited resource.

Another achievement of this project was increasing the diversity of root crops and vegetables grown in Kiribati by encouraging households to plant a variety of crops in their giant swamp taro pits. Both women and men applied compost in the pits, created terraces, and planted giant swamp taro and other vegetables in different "rooms" in the pits (Fig. 9.2).

Use of Invasive Seaweed as an Organic Fertilizer

The Pacific Small Island Developing States (PSIDS) consists of a variety of both high and low islands, each with its own characteristics of habitats, complexity of land features, as well as agricultural fertility (Thaman et al. 2002). With growing populations and the ever-increasing need for more intensive and effective food security efforts, farmers in PSIDS increasingly rely on soil additives, mainly in the form of chemical NPK (nitrogen, phosphorus, potassium) fertilizers. However these are both expensive and detrimental to the environment as sources of coastal eutrophication. Since the PSIDS are in a marine environment, marine-based substitute solutions to soil enhancement would be a natural alternative. Pacific nations such as Fiji and Tuvalu in the Central Pacific have recently been faced with algal bloom issues (N'Yeurt and Iese 2015a, b), and these events have been linked to excessive inputs of nutrients into the coastal environment. Notably, a high percentage of these anthropogenic nutrient inputs come from runoff of chemical fertilizers and manure from terrestrial agriculture.

Ongoing research at the University of the South Pacific (N'Yeurt and Iese 2015a) has demonstrated the effectiveness of seaweed fertilizer as a substitute for their chemical counterparts. Liquid fertilizers made from the brown seaweed *Sargassum polycystum* and the red seaweed *Gracilaria edulis* have been found to contain high values of the essential nutrients phosphorus and potassium, as high as 14–15 mg/L for phosphorus and up to 6 mg/L for potassium (Soreh et al. in prep.). Conversely, plant-derived fertilizers are usually low in nitrogen, and seaweed extracts fall into that category. In atolls such as Tuvalu, *Sargassum* seaweed is currently used as a fertilizer on vegetables such as tomato and cucumber, being harvested from the beaches and applied with minimal processing (usually just washing in freshwater). On the culturally important Island of Beqa in Fiji, other marine plants such as the seagrass *Syringodium isoetifolium* are used in a similar manner on tomato and kava plantations.

While not yet widespread in use, seaweed-derived fertilizers in both unprocessed and processed (liquid, composted) form have a very high potential to replace chemical fertilizers, with a much lesser impact on the environment. The deficiency in nitrogen found in marine-plant-based fertilizers could be easily addressed by blending with protein-rich compost produced from animal sources, such as fishmeal or even the coral-eating crown-of-thorn starfish (COTS). Work in progress by the authors and colleagues on COTS-based fertilizer is very encouraging, and the production of cost-effective, nutritionally balanced organic fertilizers based on marine pest species is now an attractive reality for farmers in SIDS. Such initiatives, in addition to contributing to the food security of local communities, can have significant impacts on economic security through the sale of excess fertilizer to other farmers and the community at large. An overarching additional benefit is the reduction of marine pest species and a decrease in the input of excess nutrients in coastal waters, promoting healthy marine ecosystems such as coral reefs, seagrass beds, and coastal mangroves which are each in their own right bountiful sources of food security for local PSIDS communities.

Use of Mucuna to Improve Soil Fertility and Resilience

The important role of mucuna in improving soil fertility was proven during field trials conducted in Taveuni, Fiji (Lal 2013), and four locations in Samoa (Anand 2016). The continuous cultivation of taro in Taveuni for 30 years led to reductions of yield due to low soil fertility. Farmers applied large amounts of chemical fertilizers that negatively affected the environment. The taro yields continued to decline. As a response, a research project focused on improving taro yield through the use of mucuna beans (*Mucuna pruriens*) as a fallow crop. A comparison of mucuna and a typical grass fallow with and without lime and rock phosphate applications recorded a 100% increase of Olsen available P (a measure of plant-available soil phosphorus) with mucuna fallow for both 6 and 12 months. The mucuna fallow plot also showed a 50% increase of nitrogen in 6 months and a 100% increase in 12 months of trials. For total organic carbon, a slight decrease was recorded after 6 months, but there was a significant increase of total organic carbon between 6- and 12-month mucuna fallow duration. Mucuna fallow had significantly higher biomass production and accumulated higher levels of nitrogen, phosphorus, potassium, and calcium in its foliage. Furthermore, as the durations of fallow increased from 6 to 12 months, total soil organic carbon, nitrogen, and potassium bulk density and earthworm numbers increased significantly. Overall, there was a 33.5% increase of yield of taro under mucuna fallow compared to grass fallow at Taveuni, Fiji (Lal 2013).

In a multi-agroecological site study in Samoa, fallow with mucuna and grass significantly improved soil active carbon stocks upon decomposition. Mucuna fallow contributed to the largest addition of biomass across all the agroecological sites in Samoa. Mucuna was also the most superior cover crop for improving soil active carbon and soil biological activities. The yield of taro was comparatively higher under mucuna fallow than grass fallow. Comparative economic analysis of mucuna fallow technology showed a 98% increase in gross profit for Salani and Safaatoa sites in Samoa (Anand 2016). Mucuna as a green farming technology not only increases soil health and overall yield and its associated economic benefits but also reduces labor requirements and chemical inputs. This technology is suitable to increase yield of crops in a changing climate and overcultivated lands. Both studies were funded by ACIAR through scholarships to the School of Agriculture and Food Technology, at the University of the South Pacific.

The nutritional value of crops is rarely considered in agricultural adaptation activities in PICs. This is unfortunate given the alarming rate of nutritional disorders such as anemia, vitamin A deficiency, obesity, and other nutrition related noncommunicable diseases in PICs (Thaman 1995). Studies have also implied that most protein in the highlands of PNG comes from sweet potato and other plant products. The food supplies committee in the Solomon Islands conducted a study on the production of sweet potato at household level, and the study stressed the need to increase production primarily of sweet potato in home gardening since there was a correlation between vitamin deficiency and those that do not have garden plots. In Kiribati, to combat vitamin A deficiency and anemia in heavily populated areas of South Tarawa, campaigns and competitions have been started to promote growing vegetables and fruit trees. The Foundation of the Peoples of the South Pacific International (FSPI) has been a strong advocate in Kiribati of increasing local production of vegetables that are rich in vitamin A (FAO (2018a, b)).

The case studies discussed above highlight the use of effective partnerships between national governments, regional and international institutions, universities, and local farmers to improve crop production through research, technology transfer, and climate-smart agriculture approaches. The success of agriculture in a changing climate depends on applied research and capacity building of farmers. The use of basic tools to understand the current status of soil, water, and community practices helped to provide targeted technologies, which addressed factors limiting agricultural production.

9.5 Looking Ahead: Strategic Directions for Transforming Agriculture Under a Changing Climate

This section discusses strategic directions for building resilient agriculture in PICs. It first analyzes national agriculture sector plans of PICs and distills key priorities in relation to climate change that—if effectively realized—could facilitate in the transformation of the agriculture sector going forward. The section then discusses key opportunities for realizing these priorities, including integrated vulnerability assessments, applied research, genuine partnerships, and resourcing arrangements.

9.5.1 Priorities of Agriculture Sector Plans in Relation to Climate Change

PICs have developed many strategies, policies, and plans to improve the productivity of the agriculture sector in the future, both in relation to agricultural commodities and increasing food security. Key themes/priorities in relation to building the resilience of the agriculture sector in a changing climate include healthy soils and access to land, secure and sustainable water supplies, diversification of farming systems (including agroforestry), embracing climate-smart agriculture (including reducing greenhouse gas emissions and adopting resilient crop and livestock varieties), and resourcing (see Table 9.2).

Healthy Soils, Sustainable Land Management, and Access to Land

Almost all PICs have agricultural plans that emphasize the need to maintain and enhance soil health in order to improve agricultural productivity. The case studies described in Sect. 9.4 highlight interventions that have made soil health the center of sustainable agricultural production. When soil health is maintained, organic carbon content and water-holding capacity are enhanced, and important nutrients and micronutrients are made more accessible. Healthy soils also promote pH balance and biological activity of soils, which in turn leads to increased crop resilience and yields. In a changing climate with more frequent and intense extreme events and increasing temperatures and soil salinity, PICs need to focus on improving and maintaining soil health to increase and sustain agricultural production. The agricultural plans of PICs also discuss more broadly the need to improve sustainable resource and land management.

Many lands that are suitable for farming in PICs remain unused due to communities having migrated to the urban areas or overseas. Mechanisms to facilitate access to land in these circumstances should be included in agriculture strategies at the community level. Some PICs are changing their laws to facilitate access to idle lands. For example, Fiji and Samoa have passed laws to allow the lease of custom-

Table 9.2 Key priorities relating to climate change in the agriculture and food security plans of Pacific Island Countries

Country (years of plan)	Key themes	Distillation of key themes
Samoa (2016–2020)	• Strengthen the capacity and resilience of farmers and fishers to prepare and recover from climate threats and disasters affecting agriculture and rural livelihoods • Sustainable agricultural and fisheries resource management practices in place and climate resilience and disaster relief efforts strengthened	• Build resilience and capacity of farmers and fishers • Sustainable resource/land management • Improved disaster relief
Cook Islands (2015)	• Healthy soil and conduct agroecological adaptive research • Support sustainable agriculture and its gradual adaptation to agroecological production models • An agriculture insurance package is developed in accordance with the Pacific Disaster Risk Financing and Insurance (PDRFI) program (supported by World Bank)	• Healthy soils • Sustainable agriculture • Agricultural insurance
FSM (2012–2016)	• Enhanced environmental services and sector resilience to natural disasters and climate change • Appropriate and well-managed use of trees in agricultural systems (agroforestry and home gardens) • Land management practice has much to offer in terms of nutrient cycling and ecosystem services required in organic farming	• Enhanced environmental services • Farm diversification (agroforestry and home gardens) • Sustainable land management
Fiji (2020)	• Adoption of climate change agriculture in Fiji—including agroforestry and new drainage techniques • Effective management of soil carbon • To be prepared and ensure better productivity when facing climate change, thus ensuring food security • Farmers are also contributing to the broad goal of climate change agriculture, which is to decrease greenhouse gas (GHG) emissions	• Farm diversification (agroforestry) • Healthy soils/enhanced soil carbon • Climate-smart agriculture

(continued)

Table 9.2 (continued)

Country (years of plan)	Key themes	Distillation of key themes
Kiribati (2013–2016)	• When organic matter levels in soils are improved, the soils will hold more water for plant use • Selecting varieties that are more adaptable to harsh atoll conditions and potential climate change impacts of increased temperature, drought, and seawater intrusion • Develop integrated and holistic food production systems resilient to impacts of climate change and contributing to food security • Potential development of a new pest and disease regime addressing impacts of climate change will be undertaken with capacity	• Healthy soils • Resilient varieties • Food security
Nauru (2005–2025)	• Develop locally tailored approaches and initiatives to mitigate the causes of climate change and adapt to its impacts • Practical and relevant climate change adaptation measures and initiatives implemented and sustained	• Mitigation/reduced greenhouse gas emissions
RMI (2013)	• Promote climate "smart" farming systems, and evaluate new crop cultivars to identify those which are more tolerant of drought and saline soil and water conditions • Undertake enhanced planning and interventions to address climate vulnerabilities in food security and nutrition	• Climate-smart agriculture • Food security
Palau (2015)	• Local farmers to adapt production methods to the impacts of climate change • Real-time extension services can help prevent potential losses from investments • The recovery period from the impacts of extreme storm surge and sea level rise should be researched and integrated into business plans as well as grant and loan agreements • Uses climate proofed state-of-the-art sustainable land management practices and organic practices and maximizes local inputs and renewable energy to produce 80% of Palau's food needs by 2025	• Enhanced agricultural extension services • Sustainable land management and organic agriculture • Food security
PNG (2007–2016)	• To increase land resource (soils, water, climate, geomorphology) surveys • Improve availability and quality of land resources (soils, water, climate, and geomorphology) information—acquire soil, land, and climate survey equipment	• Conduct more applied research • Increase applied research capacity and equipment

(continued)

Table 9.2 (continued)

Country (years of plan)	Key themes	Distillation of key themes
Solomon Islands (2015–2019)	• Nutrients extracted from the soils should be replaced, forests replanted, soil degraded, and overgrazing reversed • Conservation farming techniques such as agroforestry, fallow, cover crops, intercrop, and contour planting • Promote agroforestry with the use of intercropping to reduce vulnerability • Develop crops that are resilient to natural disasters • Crop insurance schemes where possible or disaster funds	• Healthy soils • Conservation farming • Farm diversification (agroforestry) • Resilient varieties • Agricultural insurance
Tonga (2016–2020)	• Healthy soils, secure and sustainable water, diverse farming systems, and adaptive communities. • Develop a climate-resilient environment—low-carbon, climate-resilient farming systems • “Future Farmers Programme”—return to family farms and to become climate-resilient subsistence and/or commercial farmers and change agents within their communities • Soil fertility tools, agrometeorology, crop models, and technology transfer for food processing	• Healthy soils • Food security • Climate-smart agriculture
Vanuatu (2016)	• Mainstream climate variability, climate change and disaster risk reduction using adaptation and mitigation strategies in all agriculture initiatives and developments • Build risk reduction capacity of farming communities through training and awareness to adapt and mitigate effects of climate variability, climate change, and natural disasters • Promote mitigation strategies in all farming practices • Prioritize the introduction of climate- and risk-resilient crops for cultivation by farmers • Provide adequate funding for activities to address climate variability, climate change, and disaster risk reduction	• Mainstream adaptation and mitigation strategies in agriculture • Risk reduction and capacity building at the community level • Reduce greenhouse gas emissions • Resilient crops • Resourcing

ary lands for longer periods of time for agriculture and development purposes (iTaukei Land Trust Board 2019; Government of Samoa 2008).

Sustainable Water Supply for Agriculture

Sustainable water supply in Pacific agriculture is important, but Tonga is the only country that has included the need for sustainable water supply in their agriculture sector plan. The impacts of drought on agriculture are becoming more prominent in PICs. Droughts can last for months or years, and farmers and governments are finding it hard to respond and recover. Lack of water destroys plants and livestock, while droughts also tend to be associated with high temperatures that dry out soils, making them hard to cultivate for the following season. Availability of water for irrigation during droughts is a major problem for farmers. Atolls and low-lying islands with no rivers rely heavily on rainfall for growth of crops. For high islands with rivers, long distances between farms and water sources and lack of finances and equipment for irrigation are the main issues with setting up irrigation systems. Measures for increasing the availability of water in PICs should be considered in agriculture sector plans. Solutions for increasing sustainable water supply will be different for atoll islands and higher islands with rivers, but measures could include water storage infrastructure, water distribution infrastructure, and technologies that increase water use efficiency such as smart water meters.

Diverse Farming Systems

Traditionally, the agriculture systems of PICs are organic and highly diverse including livestock, vegetables, spices, and culturally important plants. The diversity of traditional agriculture systems has enabled Pacific communities to provide food for themselves and survive many disasters. Households cultivate home gardens with different types of crops and plants that are used for food, medicine, adornment during dances, and decorating buildings during special occasions. Home gardens should be encouraged in urban areas where land is limited. Agroforestry farming is another technology that has been widely practiced in PICs to increase diversification. With this type of farming, the combination of crops, trees, and livestock can promote productivity while maintaining the balance of the ecosystem, including soil, air, water, and environmental health. Many PICs promote farm diversification in their agriculture sector plans, including Tonga, Solomon Islands, Fiji, and FSM.

Climate-Smart Agriculture

Climate-smart agriculture is an approach that aims to sustainably increase agricultural productivity by building the resilience of the agriculture sector to climate change impacts while reducing greenhouse gas emissions from the sector where

Table 9.3 Mitigation sectors in the Nationally Determined Contributions of PICs submitted to the UNFCCC

Country	Electricity	Energy	Transportation	Waste	Agriculture
Samoa	√				
Cook Islands	√				
FSM	√	√	√		
Fiji	√	√			
Kiribati	√	√			
Nauru	√				
RMI	√	√	√	√	
Palau	√		√	√	
PNG	√				
Solomon Islands	√	√	√		
Tonga	√	√	√	√	√
Vanuatu	√				

Source: Redrawn from Lloyd (2018)

possible (FAO (2018a, b)). The term encompasses many activities, some of which have been practiced in PICs for a long time. Activities that qualify as illustrations of climate-smart agriculture include the promotion of agroforestry, soil organic carbon sequestration, organic agriculture, and the use of early warning systems and agrometeorology in farming systems.

Climate-smart agriculture also includes activities to reduce greenhouse gas emissions from agriculture. About six countries include mitigating greenhouse gas emissions and practicing low-carbon agriculture in their agriculture policies. However, only Tonga has included the agriculture sector as a mitigation sector in their Nationally Determined Contributions (NDCs) report to the UNFCCC (see Table 9.3).

Focus on Food Security

There is a need to increase and sustain agricultural production for food security and livelihoods in Pacific communities. Many PICs mention food security as a priority in their agriculture sector plans; however, agriculture ministries and departments tend to focus more on supporting large-scale farmers to increase yields of commodity crops, rather than a "food first" approach based on agriculture as a system rather than a commodity. In national agriculture planning and development, commercial farmers or representatives of farmers associations (who are mostly commercial farmers) are represented, but rural farmers or subsistent/semi-subsistent farmers are rarely included. Support should be given to subsistence farmers to improve production and help them become semicommercial farmers. Pathways should be initiated and supported to facilitate the "readiness" of communities to invest in value adding to agricultural products.

9.5.2 Opportunities for Transforming the Agriculture Sector

The priorities for future agriculture development in a changing climate are very clear in national agriculture policies and in many ways mirror the good practices illustrated in the case studies discussed in this chapter. The key challenge going forward is realizing these priorities. The discussion below focuses on opportunities for realizing the priorities discussed above. These opportunities relate to integrated vulnerability and risk assessments, applied research, building and utilizing effective partnerships, and securing resources.

Vulnerability and Risk Assessments of Food Security and the Agriculture Sector (Before, During, and After Hazards)

The use of integrated vulnerability assessment tools is useful for understanding the current and future exposure of agriculture systems to climatic hazards and how they will impact crop growth, yield, food nutrition values, soil nutrients and carbon, water availability, and markets. A production index should also be included in the assessments to identify the limiting factors to agricultural production. Baseline information of current soil profiles, land use, landforms and availability maps, short-term projections of rainfall, cyclones, sea level rise, temperature, and historical impacts should be established in each country. Proper agroecological zones should be established based on soil types, landscape, and weather patterns to map vulnerability at specific sites. Tools and technologies such as participatory rural appraisal, soil testing kits, water collection and distribution systems, soil water meters, and GIS technologies should be supported. Agriculture decision support tools such as crop simulation models or impact models should be applied to provide important information to support communities to understand current, short-term, and long-term risks of climate change on agriculture.

Applied and Accessible Research

Ongoing agriculture and climate change research supported by national governments, private sector, NGOs, research organizations, universities, and farmers is generating important knowledge, skills, and information farmers need in order to build the resilience of PICs' agriculture systems. Previous research has ranged from evaluation of resilient crops and livestock, soil health and water availability, agroforestry, ecosystem-based adaptation, traditional coping mechanisms to reduce risks, development and application of crop models and impact models to assess impacts of climate change on crops and livestock, and how to reduce losses and damages in the agriculture sector. Unfortunately, these research projects have been driven by external donors and have usually only involved a small number of local stakeholders such as government officers in research stations or commercial farmers.

This has meant that the application and adoption of research findings by farmers and communities in PICs has generally been limited. There are also issues with the accessibility of many research products, which are generally written in English using highly technical language and are kept in hard copy in libraries or government offices. Many of these publications have never reached the hands of farmers or policy-makers and have therefore colloquially been named “dusty technologies.” Publications should be simplified, translated into the local language, and digitized so that they can be shared more widely.

Crops that are deemed to be resilient (which are kept in national and regional germplasm centers) should be properly evaluated both before and after distribution to farmers. For example, crop simulation models can be used to simulate potential yields of crops such as taro, sweet potato, and cassava before distribution and to develop crop profiles on how, when, and where to plant. Farmers should also be supported to document the performance of resilient varieties in the field, as there is a lack of evaluation in how resilient varieties—many of which have come from overseas—perform in PICs.

Standardized methods should be developed to monitor the effectiveness and efficiency of adaptation and mitigation actions in the agriculture sector. To date, monitoring and evaluation tends to be donor driven and project-focused and usually does not extend beyond the lifetime of projects. There is a need for cross-project evaluation methods that measure progress toward the goals and objectives of agriculture sector plans. The best practices generated from evaluation of adaptation and mitigation initiatives will help inform where limits to adaptation exist and when transformational, “step-change” approaches are needed. This would involve determining what level of risks (arising from droughts, cyclones, saltwater, floods, poor soil) an adaptation option can tolerate in different countries and communities before residual losses occur. Developing risk tolerance and adaptation limits will assist decision-making on what type of adaptation option to adopt, what types of technology transfer are needed, and at what point new, innovative, or “transformational” approaches need to be devised. Such approaches will enable PICs to document residual loss and damages.

Genuine Partnerships

Agriculture is a sector that stretches from the ridge to the reefs—involving different formal and informal sectors, different land tenure systems, diverse ecosystems, and different regional and international development partners. Continuously engaging different partners and stakeholders in decision-making and in sharing resources and capacity when implementing activities is crucial. This reduces competition for roles and improves complementary actions for growth of the agriculture sector. The involvement of the private sector, NGOs, farmer associations, and subsistence farmers in agriculture research, innovation, and information sharing should be supported.

Resourcing

All Pacific Island governments allocate less than 5% of their national budgets to the agriculture sector. Resources for the implementation of national agriculture policies mainly come from development partners. The overreliance on development partners for funding tends to result in an overabundance of pilot projects and a lack of follow-through to scale up best practices. The lack of capital and investment in technologies such as irrigation, crop models, soil testing kits, GIS and remote sensing tools, and resilient cropping systems is continuing to expose crops and trees to adverse impacts of extreme events and climate change, therefore affecting farmers and communities. All PIC governments should increase budget allocations to the agriculture sector if they sincerely plan to increase the resilience of the sector.

Cook Islands and Solomon Islands have prioritized development of an insurance scheme for the agricultural sector to transfer risks associated with climate change. This will help farmers recover faster after disasters (Table 9.2). Insurance for farmers has been successfully introduced in other regions of the world (Linnerooth-Bayer and Mechler 2009), and it should be considered as an important risk transfer mechanism to support farmers to cover losses from disasters in PICs. A major challenge is setting insurance premiums at a level that is affordable to households across the Pacific and convincing households that insurance is a worthwhile investment. To help reduce insurance premiums, there may be a case for the establishment of public-private partnerships between the insurance industry and different levels of government to invest in risk reduction measures. Governments of PICs could also consider providing subsidies on insurance premiums to incentivize the uptake of insurance products.

Another opportunity for securing resourcing to transform the agriculture sector is the Green Climate Fund and other climate change and disaster risk reduction funds. The Green Climate Fund supports both adaptation and mitigation. Despite the fact that all countries of the Pacific prioritized agriculture or food security resilience in their national adaptation plans, out of the eight PICs that have had project proposals approved by the Green Climate Fund, only Vanuatu included climate services for farmers and forestry in their activities, and only Tonga included agriculture as a mitigation sector in their Nationally Determined Contributions (NDCs) submitted to the UNFCCC. Many of the practices that increase the resilience of the agriculture sector in PICS also have mitigation co-benefits. For example, practicing agroforestry and increasing soil health and carbon sequestration increase the resilience of agricultural production while reducing greenhouse gas emissions. PICs should consider including the agriculture sector in project proposals to the Green Climate Fund and other climate change and disaster risk reduction funds. There are many small-scale projects that are producing best practices and increasing agricultural productivity at the community or sub-national levels. The good practices from these projects should be upscaled and shared more widely. The upscaling of good agricultural practices can be funded by the communities themselves, governments, private sector, NGOs, and development partners.

The priorities of the agriculture plans discussed above are closely aligned with priority areas for intervention at the international level with the Koronivia Joint Work on Agriculture Initiative (hereafter the Koronivia Initiative), a decision that came out of the UNFCCC COP 23 meeting in Bonn. The Koronivia Initiative recognizes methods for assessing adaptation co-benefits, embracing integrated systems for soil carbon, health and fertility and water management, improved manure and nutrient management, improved livestock management systems, and the importance of food security dimensions (ECBI 2018). The Koronivia Initiative aims to support implementation; facilitate knowledge sharing, capacity building, and technology transfer; and aid in the mobilization of finance (CCAFS 2018; UNFCCC 2017). The close alignment between the key priorities of the national agriculture sector plans of PICs and the Koronivia Initiative presents opportunities to seek resourcing support.

9.6 Conclusion

The agriculture sector in PICs is critically important for food security and livelihoods at the household, community, national, and regional levels. Climate change is already impacting and will continue to impact agriculture in both the short and long term. PICs need to transform the agriculture sector for it to remain prominent and relevant in Pacific communities. There is a need for the agriculture sector in PICs to become resilient to the negative impacts of climate change while simultaneously increasing production to feed a growing population. In addition, there is a need to reduce the negative environmental impacts of unsustainable agriculture on soil, waterways, and the atmosphere (through the release of greenhouse gas emissions). Agricultural transformation can be achieved in PICs through focusing on a systems-oriented perspective that recognizes the foundational importance of healthy soils. Opportunities exist to strengthen existing partnerships and forge new ones to address information and resourcing constraints.

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