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Climate Change Implications for Crop Production in Pacific Islands Region

Morgan Wairiu, Murari Lal and Viliamu Iese
Pacific Centre for Environment and Sustainable Development,
University of the South Pacific,
Fiji

1. Introduction

Climate plays an important role in crop production since plants require suitable temperature, rainfall and other environmental conditions for growth and development. Changes in temperature and rainfall would affect crop production, the degree of which varies with latitude, topography, and other geographic features of the location (Huey-Lin Lee, 2009).The IPCC 4th Assessment Report in 2007 predicted that the intensity of climate change especially temperature will increase in the future and stressed that many Pacific islands will be among the first to suffer its impacts. It further reported with high confidence that it is very likely that subsistence and commercial agriculture on small islands like those in the Pacific region will be adversely affected by climate change. The Asian Development Bank (2009) report also stressed that the Pacific Islands Countries and Territories (PICTs) are amongst some developing countries that are likely to face the highest reductions in agricultural potential in the world due to climate change. Furthermore, Secretariat of Pacific Regional Environment Programme (2009) emphasized that climate change impacts will be felt not only by current population but for many generations in the Pacific region because of the small island countries' high vulnerability to natural hazards and low adaptive capacity to climate change. The PICTs total land area is only 553 959 km^2 while they spread over almost 20 million km^2 of ocean. In other words, Pacific Islands land covers only 2 percent of the total Pacific region and Papua New Guinea (PNG) accounts for 83 percents of that total land area. The islands and their inhabitants are continuously exposed to a range of natural hazards, including cyclones, storm surges, floods, drought, earthquakes and tsunamis. The region's limited land area and vast ocean support the livelihood of approximately 9 million people (FAO, 2008).

The purpose of this chapter is to bring to the fore implications of climate change on the status of crop production in the Pacific Islands region. The Pacific Island people derive their livelihood or secure their food security from natural resources sectors including agriculture, forestry, fisheries and aquaculture; that is, their livelihood is depended on the environment. Any threat or impact on their environment will have profound impact on people's livelihoods. The PICTs limited land resources are under constant pressure from many factors including climate change. Agricultural crops contribute substantially to people's food security status.

2. Physical and natural environment of the Pacific region

The PICTs vary significantly in size, from PNG with a total land area of 460,330 km^2 to Nauru and Tuvalu that are smaller than 30 km^2 (FAO, 2008) The islands also have marked differences in geological resources, topographical features, soil types, mineral and water availability, diversity of terrestrial, freshwater and marine flora and fauna. Many Island countries especially the atolls have poorly developed infrastructure and limited natural, human and economic resources, and their populations are dependent on limited land and marine resources to meet their food requirements. The high islands support large tracts of intact forests including many unique species and communities of plants and animals.

The SPREP 2009 report described most of PICTs environment and development status in detail. Most of the PICTs economies are reliant on a limited resource base and are subject to external forces, such as changing terms of trade, economic liberalisation, and migration flows. The report further stated that demand by global market economies and increasing population of PICTs is resulting in significant commercial and subsistence harvesting of limited natural resources at unsustainable level. The activities include unsustainable logging, cultivation of steep and marginal lands, monocropping for commercial purposes, infrastructure development and mining. In the last 30 years, many terrestrial ecosystems have been heavily disturbed and degraded, increasing their vulnerability to global environmental changes including climate change. Further, the PICTs are located in the vast Pacific Ocean and are prone to natural hazards often of geological nature.

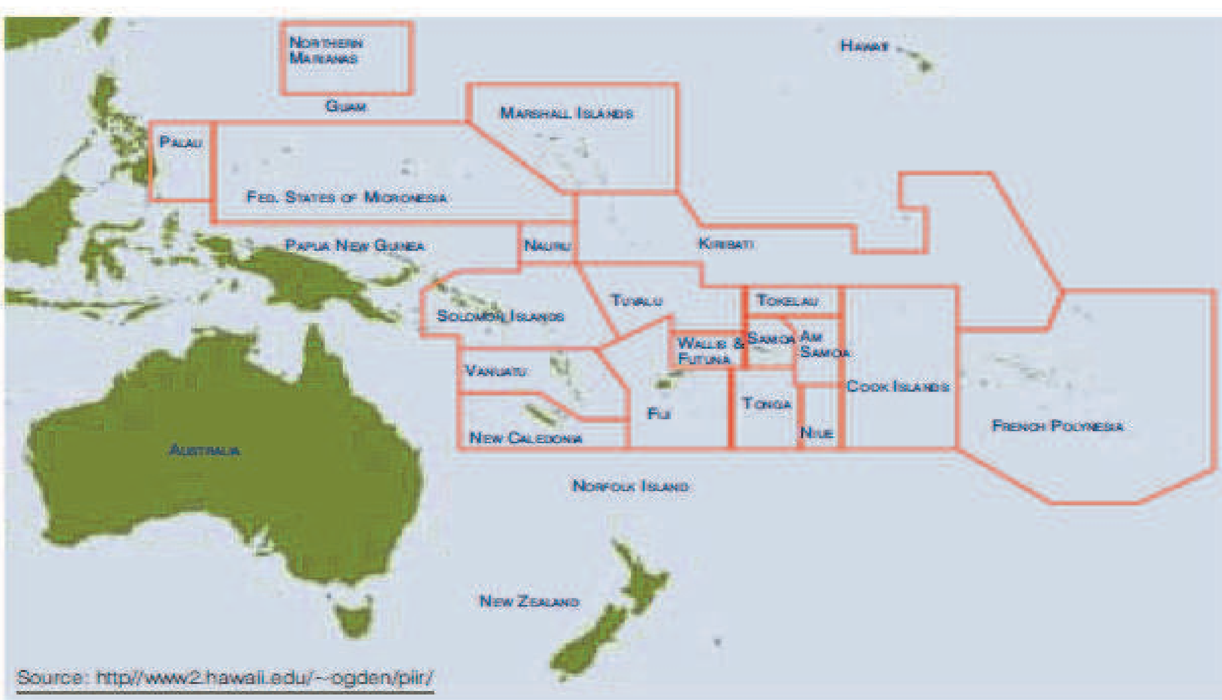

Fig. 1. Map showing location of PICTs

The region hosts a population of approximately 9 million, a number expected to increase substantially by 2030 (FAO, 2008). The population densities vary from just over one person per kilometer for Pitcairn Island to almost 300 or more for Nauru and Tuvalu. The majorities of the population live in rural areas and rely heavily on agriculture, forestry and fisheries as a source of food security. However, urbanization is taking place very fast resulting in more than 40 percent of population residing in urban areas especially in small and atoll countries for example Kiribati and Tuvalu, putting pressure on fragile limited land and aquatic resources. Despite the strong geographical and cultural differences that characterize the region, many PICTs share common ecological and economic vulnerabilities especially to environmental and climate change.

3. Agriculture and crop production profile of Pacific region

The agriculture sector support the livelihoods of many Pacific islanders but it is one of the most vulnerable sectors to climate change. More than 70 percent of population in PICTs directly or indirectly relies on agriculture as a source of livelihood (ADB, 2009). Crop production practices in terms of size and production systems are just as diverse according the geographical diversity of the islands. For example, some diverse agricultural systems include the lowland sago management in PNG, systems of intensive dry cultivation of yams in Tonga, sunken fields dug to tap subsurface water for giant swamp taro cultivation on atolls in Kiribati and Tuvalu, and the remarkable landscapes of irrigated and bunded pond-fields for growing taro in New Caledonia and Fiji (Bellwood, 1989). McGregor (2006) classified the PICTs into three categories based on their diverse natural resource base and size. The larger island countries include Papua New Guinea (almost 90 percent of land area), Solomon Islands, Vanuatu and Fiji. These are mainly volcanic and generally rich in biological and physical resources. In marked contrast, the atoll countries (Federated States of Micronesia, Kiribati, Nauru, Niue, the Republic of the Marshall Islands, Tuvalu and Palau) are small, have limited natural resources and poor soils. The remaining countries (Cook Islands, Tonga and Samoa) fall in between the two categories above. The PICTs categories are shown in Table 1.

Almost all subsistence food, domestically marketed food, and export cash crops are grown by rural villagers on land that they access through customary land tenure arrangements or lease from traditional land owners. The mix of subsistence food production and small scale income generating activities can be broadly divided into:

- domestically marketed food (root crops and vegetables)
- export commodity crops (tree and root crops)
- minor cash crops (nuts and spices)
- livestock

		Land area (ha)	Arable land area (ha)	Population*	% Rural	Geographic	Importance of agricultural sector
Group 1 Relatively larger countries of Melanesia	Papua New Guinea	46,224,300	231,122	5,100,00 (2003)	85	High islands – a few small atolls	- Fundamental – overwhelming source of employment – provides a substantial proportion of net export earnings – subsistence a significant component of GDP

		Land area (ha)	Arable land area (ha)	Population*	% Rural	Geographic	Importance of agricultural sector
	Solomon Islands	2,853,000	17,118	515,870 (2009)	84	High islands – a few small atolls	Fundamental – overwhelming source of employment – provides a substantial proportion of net export earnings – subsistence a significant component of GDP
	Fiji Islands	1,827,200	168,102	837,271 (2007)	49	High islands, a few minor atolls	Fundamental – main employer and net foreign exchange earner, subsistence a significant proportion of GDP
	Vanuatu	1,219,000	207230	234,023 (2009)	76	High islands – a few small atolls	Fundamental – overwhelming source of employment – provides a substantial proportion of net export earnings – subsistence a significant component of GDP
	New Caledonia	1,910,300		220,000 (2000)		High islands	Important, particularly in the south
Group 2 Middle – sized countries of Polynesia	Samoa	293,500	25,828	178,200 (2003)	78	High islands	Fundamental – traditional agriculture the underlying strength of the economy
	Tonga	74,700		108,200 (2003)	57	High islands – a few small atolls	Fundamental – agricultural led economic growth in recent past

		Land area (ha)	Arable land area (ha)	Population*	% Rural	Geographic	Importance of agricultural sector
	Cook Islands	23,700		20,400 (2002)	30	High islands and atolls	Important – main export earner – subsistence a significant component of GDP
	French Polynesia	352100		233,500 (2000)		High islands and atolls	Some – small export earnings, domestic cash income, and subsistence
Group 3 Resource poor micro, predominantly atoll, states	Federated States of Micronesia	70,100		133,150 (2000)		High islands and atolls	Some – small export earnings, some domestic cash income, and some subsistence
	American Samoa	20,000		68,700 (2002)		High islands, with a few atolls	Minor – some subsistence and limited gardening
	Guam	54,100		163,941 (2003)		High island	Limited – some domestic market gardening
	Kiribati	81,100		98,600 (2003)	54	Predominantly atolls	Considerable – important for subsistence – copra important for out-island cash income and some foreign exchange
	Marshall Islands	72,000		73,600 (2002)	30	Atolls	Limited – some subsistence income earned from copra
	Nauru	2,100		12,329 (2001)		Raised coral island	Insignificant
	Niue	25,900		2,145 (2003)	68	Raised coral island	Significant – subsistence and some root crop exports
	Palau	48,800		19,000 (2001)	23	High islands and atolls	Some – market gardening
	Tokelau	1,000		1,400 (2003)		Atolls	Some subsistence

		Land area (ha)	Arable land area (ha)	Population*	% Rural	Geographic	Importance of agricultural sector
	Tuvalu	2,600		11,000 (2002)	58	Atolls	Some – subsistence and some cash income from copra
	Wallis and Futuna	25,500		14,900 (2003)		High islands and atolls	Some subsistence

Table 1. Pacific Island Countries and Territories Categories (adapted from McGregor 2006 and Secretariat of Pacific Community's Pacific Regional Information System, 2011)

Subsistence crop production represents a major strength of the PICTs economy because of the ability of people to feed themselves and support each other during periods of disasters, loss of cash income, and times of displacement. These traditional arrangements vary somewhat between the PICTs, and they are changing in response to modern economic development shifts and changing environment. Crop production involve cultivating, harvesting and managing food crops from different environments, the most important being shifting cultivation gardens, but also including fallow forests, primary forest, swamps and mangroves (Jansen et al., 2006). Soil fertility in gardens is maintained through a bush fallow in most cropping systems. However, subsistence crop production can sometimes fail, because of increasing population, diseases, pest and invasive species outbreaks, and extreme weather which interrupt with planting cycles. Climate change is now resulting in high frequency and severity of extreme weather events such as cyclones, drought, and excessive rainfall which impact on crop production. Many tropical crops such as yams (*Dioscorea spp.*), taro (*Colocasia esculenta*), cassava (*Manihot esculenta*) and sweet potatoes (*Ipomoea batata*) and other crops such as bananas (*Musa spp*.) and watermelon (*Citrullus lanatus*) form part of people's staple diet. For example, sweet potato is the most important subsistence crop in PNG, Solomon Islands and Vanuatu, while taro and cassava in Fiji, Samoa and Tonga. Sweet potato accounted for around 65 percent of the estimated 432 000 tonnes of staple food produced in 2004 in Solomon Islands (Bourke et al., 2006). For atoll islands, giant swamp taro (*Cyrtosperma chamissonis*) breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*) are the main crops grown.

4. Observed changes in climate, trends and future projections

Historical climate data for the PICTs is limited, but there is some evidence of a trend towards warmer and drier conditions over the past 100 years. Despite limited climate data for the region, there is evidence that the climate is changing (FAO, 2008). The annual and seasonal ocean surface and island air temperatures increased from 0.6 to 1.0°C since 1910 throughout a large part of the South Pacific and decadal increases of 0.3 to 0.5°C in annual temperatures to the southwest of the South Pacific Convergence Zone (SPCZ) since 1970 (Folland et al., 2003). Hay et al. (2003) also reported that sea surface temperatures in the region have increased by about 0.4°C. At national level, the annual mean surface air temperature has increased by 1.2 °C since the reliable records began in Fiji, representing a rate of 0.25 °C per decade (Mataki et al., 2006). There was significant increase in the annual number of hot days and warm nights, and significant decrease in the annual number of cool days and cold nights, particularly in years after the onset of El Nino in the period 1961 to 2003 but extreme rainfall trends were generally less spatially coherent than extreme temperatures (Griffiths et al., 2003; Manton et al., 2001). Mataki et al. (2006) also examined the changes in the frequency of extreme temperature events and found that significant increases have taken place in the annual number of hot days and warm nights for both Suva and Nadi in Fiji, with decreases in the annual number of cool days and cold nights at both locations. The number of hot days (max temperature ≥32 °C) shows a significant increasing trend while the number of colder nights (min temperature < 18 °C) showed a decreasing trend at Suva. It is predicted that average temperatures are expected to rise by between 1.0 and 3.1°C. Air temperature could increase to 0.90°C -1.30°C by 2050 and 1.6°C -3.4°C by 2100 (World Bank, 2006).

The southern Pacific is now experiencing a significantly drier and warmer climate (by 15 percent and 0.8°C, respectively). The Central Equatorial Pacific, by contrast, is experiencing more intense rain (representing a change of about 30 percent) and a similarly hotter climate (0.6°C). There has been a small increase over ocean and small decrease in rainfall over land since 1970's. An analysis of monthly rainfall patterns at Goroka in Eastern Highlands Province of PNG from 1946 to 2002 found that there had been a shift to longer, but less pronounced, rainy seasons. Throughout the lowlands and highlands, villagers report similar changes in rainfall patterns. These changes are also linked in part to an increased frequency of El Nino events (Allen & Bourke, 2009). Observed rainfall at Nadi from 1941 to 2005 shows a large inter annual variability with no significant long term trend but there has been an increase in the frequency of extreme rainfall events over recent decades, a trend which is likely to continue into the future (GoF, 2011). The projected increases in surface air temperature and rainfall shown in table 2.

The global sea level gradually rose during the 20th century and continues to rise at increasing rates (Cruz et al., 2007). Small islands in the Pacific are particularly vulnerable to rising sea levels because of their proximity to the El Niño Southern Oscillation. Fifty-years or longer time-series data for sea-level rise from four stations in the Pacific reveal that the average rate of sea-level rise in this sub-region is 0.16 centimeters (cm) a year. Twenty-two stations with more than 25 years worth of data indicate an average rate of relative sea-level rise of 0.07 cm a year (Bindoff et al., 2007). In Asia and the Pacific, the sea level is expected to rise approximately 3–16 centimeters (cm) by 2030 and 7–50 cm by 2070 in conjunction with regional sea level variability (Preston et al., 2006). In Fiji over the period from October 1992 to December 2009, sea level increased by 5.5 mm per year, after taking into account the inverted barometric pressure effect and vertical movements in the observing platform. This is far greater than the estimated range of global sea-level rise over the past century, namely 1 to 2 mm per year.

Sea level is expected to rise between 9 and 90 cm by the end of the century, with the western Pacific experiencing the largest rise. Sea level rise is also likely to affect groundwater resources by altering recharge capacities in some areas, increasing demand for groundwater as a result of less surface water availability, and causing water contamination due to rising sea levels. Climate scenarios predict up to 14% loss of coastal land due to sea level rise and flooding by 2050 (Feresi et al., 2000), which are the prime coastal areas for economic activities including crop production.

Factor/Variable	Observation	Projections/Scenarios
Temperature	0.6 to 1.0 increase since 1910 0.3 to 0.5 decadal increase since 1970	Air temperature could increase 0.9˚ - 1.3°C by 2050 and 1.6 -3.4°C by 2100.
Rainfall	Small decrease over land since 1970's Small increase over ocean since 1970's	Rainfall could either rise or fall. Most models predict an increase by 8-10 percent in 2050 and by about 20 percent in 2100, leading to more intense floods or droughts
Sea Level Rise	Relative sea level rise of 0.6 to 2.0 mm yr^{-1} since 1950	Sea level could rise 0.2 meters (in the best-guess scenario) to 0.4 meters (in the worst-case scenario) by 2050. By 2100, the sea could rise by 0.5-1.0 meters relative to present levels. The impact would be critical for low-lying atolls in the Pacific, which rarely rise 5 meters above sea level. It could also have widespread implications for the estimated 90 percent of Pacific Islanders who live on or near the coast
El Nino		The balance of evidence indicates that El Niño conditions may occur more frequently, leading to higher average rainfall in the central Pacific and northern Polynesia. The impact of El Niño Southern Oscillation (ENSO) on rainfall in Melanesia, Micronesia, and South Polynesia is less well understood
Cyclones	Noticeable increase in frequency of category 4 and 5 cyclones since 1970	Cyclones may become more intense in the future (with wind speeds rising by as much as 20 percent); it is unknown, however, whether they will become more frequent. A rise in sea surface temperature and a shift to El Niño conditions could expand the cyclone path poleward, and expand cyclone occurrence east of the dateline. The combination of more intense cyclones and a higher sea level may also lead to higher storm surges

Source: (Bindoff et al., 2007; Cruz et al., 2007; Folland et al., 2003; Hay et al., 2003)

Table 2. Observed and predicted temperature, rainfall and Sea level rise.

Historical records on occurrences of extreme events like cyclones, storm surges, flooding and drought show that they are increasing in intensity or severity. Cyclones are expected to increase in intensity by about 5–20 percent. Storm frequency is likely to increase in the equatorial and northern Pacific. In general, the future climate is expected to become more El-Nino like, resulting in more droughts in the southern Pacific and more rain and consequent floods in the equatorial Pacific. Hurricane-strength cyclones; those with winds stronger than 63 knots or 117 km/hr have increased systematically in the southwest Pacific, a trend that has also been observed at the global level over the past 30 years (Emanuel, 2005; Webster et al., 2005). The region now experiences on average four hurricane-strength cyclones a year.

5. Impacts of climate change and climate variability on agriculture and crop production

Climatic change is already influencing agriculture and crop production in the PICs but Allen and Bourke (2009) caution that it is too early to draw conclusions since there is not enough information about probable changes in temperature and patterns of rainfall and rainfall extremes and furthermore agricultural responses to climate change will be complex because other factors affecting crop production will also at play. This may be true for effects of changing temperature and rainfall but other effects are obvious. The direct or immediate impacts of climate change on agriculture and crop production occur during or immediately after a natural hazard or extreme event, such as damage to crops, farmlands and agriculture infrastructure from cyclones and flooding. The World Bank (2006) reported that during the period 1950 to 2004, about 207 extreme events were recorded in the pacific region and the cost of climate-related disasters on the agricultural crops is estimated to range from US$13.8 million to US$14.2 million. Ten of the 15 most extreme events reported over the past half a century occurred from 1990 onwards as shown in table 3. There has been a substantial increase in the hurricane-strength cyclones since the 1950s with an average of four events in a year. Similarly, the number of reported disasters in the Pacific Islands region has also increased significantly since the 1950s and disasters are becoming more frequent with increasing intensity of extreme events. This period also registered 96 (50 percent) of the 192 minor disasters.

Cyclones are the most common extreme event and caused more disaster in the region. Cyclones accounted for 76 percent of the reported disasters from 1950–2004, followed by earthquakes, droughts and floods. The average cyclone damage to PICTs economies during this period was US$75.7 million in real 2004 value (World Bank, 2006). In New Caledonia, the estimated cost of damage to agriculture by cyclone Erica in March 2003 was US$13 million (Terry et al., 2008) while Cyclone Ami that hit Vanua Levu in Fiji in 2003, caused US$33 million loss (McKenzie et al., 2005), mainly due to flood damage of agricultural crops and infrastructure. In 2004 cyclone Ivy affected over 80 per cent of food crops in Vanuatu and cyclone Val in 1991, hit Samoa with maximum wind speeds of 140 knots causing massive damage; equivalent to 230 per cent of the country's real 2004 GDP (World Bank, 2006).

Drought, an extreme form of rainfall variability can affect the highest number of people per event. El Niño event in the past has resulted in water shortages and drought in some parts of the Pacific (e.g. PNG, Marshall Islands, Samoa, Fiji, Tonga and Kiribati), and increased

Event	Year	Country	Estimated losses
Cyclone Ofa	1990	Samoa	140
Cyclone Val	1991	Samoa	300
Typhoon Omar	1992	Guam	300
Cyclone Nina	1993	Solomon Islands	–
Cyclone Prema	1993	Vanuatu	–
Cyclone Kina	1993	Fiji	140
Cyclone Martin	1997	Cook Island	7.5
Cyclone Hina	1997	Tonga	14.5
Drought	1997	Regional	> 175[a]
Cyclone Cora	1998	Tonga	56
Cyclone Alan	1998	French Polynesia	–
Cyclone Dani	1999	Fiji	3.5

– Not available.
a. Includes losses of US$160 million in Fiji (Stratus 2000).

Table 3. Number of cyclones and cost of damage from 1990 to 1999(Source: World Bank, 2000)

precipitation, and flooding in others (e.g. Solomon Islands, and some areas in Fiji) (World Bank, 2000). In Fiji, the 1997/98 drought events resulted in 50 percent loss in sugarcane production and total losses in the industry were around US$50 million while other agriculture losses including livestock death amounted to around US$7 million (McKenzie et al., 2005). An extension of the dry season by 45 days has been estimated to decrease maize yields by 30 to 50 percent, and sugar cane and taro by 10 to 35 percent and 35 to 75 percent respectively (Hay et al., 2003). In Kiribati, breadfruit and banana crops suffer from drought stress resulting in lower yields (GoK, 2007). A drought associated with a severe El Nino-Southern Oscillation event in 1997, caused significant disruptions to village food and water supplies in PNG. There were severe shortages of food and water, with garden produce declining by 80 percent. Up to 40 percent of the rural population (1.2 million people) were without locally available food by the end of 1997 (Allen & Bourke, 2001). Crop production in many PICTs is effected by extreme drought events.

Increases in minimum and maximum temperature are already having a small influence on agricultural production and will have a greater influence in the future. For example in PNG, it was observed that tuber formation in sweet potato was significantly reduced at temperatures above 34 °C. Maximum temperatures in the lowlands of PNG are now around 32 °C, so an increase of 2.0–4.5 °C within a hundred years could reduce sweet production in lowland areas (National Agriculture Research Institute, 2011). In Solomon Islands, taro production has been reduced (less tubers and lower yields) in coastal areas over the years because of wave overtopping and warmer temperatures (GoSI, 2008). It was also observed that increase in temperature in PNG highlands has a severe impact on coffee production from *coffee rust* attack. Coffee rust is present in the main highland valleys at 1600–1800 m above sea level and a rise in temperature is likely to increase the altitude at which coffee rust has a severe impact on coffee production. Taro blight, a disease caused by the fungus *Phytophthora colocasiae*, also reduced taro yield at higher altitudes. The fungus is sensitive to temperature and a small rise in temperature could increase incidence of taro blight disease than occurs now. Some tree crops are bearing at higher altitude in the highlands but the lower altitudinal limit of some crops, such as Irish potato, Arabica coffee, and *karuka* (*Pandanus julianettii* and *P. brosimos*), will increase because of increasing temperatures(Allen & Bourke, 2009). In Fiji, the major concern of sugar production is the sporadic sucrose content in the yield which could be affected with increase in temperature, groundwater salinization and fluctuating soil moisture content. This is a concern because sugar is a major foreign exchange earner, accounting for about 40 per cent of the country's merchandise exports and 12 per cent of Fiji's Gross Domestic Product (Gawander, 2007). The scenario for sugar cane production in Fiji over the next 50 years will be in the following manner:

- 47 percent of the years will have the expected production of 4 million tonnes,
- 33 percent of the years will have half of the expected production,
- 20 percent of the years will have three-quarters of the expected production.

This was determine when using the period from 1992 to 1999, when Fiji was subjected to two El Niño events and an unusually high number of tropical cyclones as an analogue for future conditions under climate change. The outcome under this scenario would be an overall shortfall in excess of one quarter of expected production (GoF, 2005).

Hay et al. (2003) pointed out that for the Pacific region the smaller temperature increase relative to higher latitude locations is unlikely to place a severe limitation on crop production but the physiology of crops may be influenced in ways not yet identified. Using PLANTGRO a plant growth simulation model the following patterns were projected for Taro (*Colocassia esculenta*) and yams (*Dioscorea sp.*) in Fiji (GoF, 2005):

- Projected changes in mean conditions would have little effect on taro production, with the exception of the extreme low-rainfall scenario. It is likely that yam production will also remain unaffected, although if rainfall increases significantly, yam yields may fall slightly.
- When El Niño conditions are factored in, reductions in, production of 30-40% might be recorded in one out of three years, with a further one in five years affected by the residual effects of the ENSO events.

Agricultural productivity in PICTs is heavily dependent on the seasonal rainfall. About 70 percent of the gross cropped area in the Pacific Islands is geographically located so as to benefit from rains in the summer season (November – April). While the rainfall requirements and tolerance of extremes vary from crop to crop, a working figure for the south west Pacific is that a mean annual rainfall of 1800-2500mm is optimal for agricultural production and a mean annual rainfall of over 4000mm is excessive (Bourke et al., 2006). A significant (>50 percent) increases in rainfall on the windward side of high islands during the wet season may increase taro yields by 5 to 15 percent, but would reduce rice and maize yields by around 10 to 20 percent and 30 to 100 percent, respectively (Hay et al., 2003). In PNG, most of the rural population live and cultivate crops in areas where annual rainfall is in the range 1800–3500 mm. In mountainous locations where clouds form early in the day and reduce sunlight, human settlement and agriculture is generally absent. Localities where the annual rainfall is more than 4000 mm tend to be too wet and have too much cloud cover for good agricultural production. Yields of sweet potato and other crops tend to be lower on the southern sides of the main mountain ranges, for example, in Southern Highlands Province and mountainous parts of Gulf Province in PNG. This is because of both excessively high rainfall and high levels of cloudiness (Allen & Bourke, 2009)

Climate change predictions for the region suggest prolonged variations from the normal rainfall which can be devastating to agriculture. Shift of rainfall patterns affect planting time, growing stages, harvest periods, post harvesting storage and drastically reduce total yield. Agriculture and crop production is under stress from these climatic factors but it remains difficult to predict the likely outcomes with certainty because of limited empirical data for the Pacific region. Disruptions to food production and the economy may intensify in future, given the projections for more intense tropical cyclones and precipitation variations of up to 14 percent on both sides of normal rainfall (IPCC 4AR, 2007) by the end of the century. More so, in between climate extremes, altered precipitation and increased evapotranspiration (including its intensity as well as temporal and spatial shifts) will also be of concern as these changes take root. The increase in atmospheric carbon dioxide may benefit agriculture but these positive effects are likely to be negated by thermal and water stress associated with climate change (Lal, 2004) and changes in pests' voracity and weeds' growth; loss of soil fertility and erosion resulting from climatic variability being another problem. Increasing coastal inundation, salinization and erosion as a consequence of sea level rise and human activities may contaminate and reduce the size of productive agricultural lands and, thereby, threaten food security at the household and local levels.

The most destructive impact of excessive rainfall on agriculture infrastructure and crops are flooding and waterlogging. For example, flooding during 2004/2005 and 2006/2007 caused around US$76 million and US$11 million in damages, respectively in Fiji . The cane growers' direct and indirect costs from the 2009 flood are estimated to be US$13.4 million. The costs include losses in cane output, non-cane and other farm losses, and direct and indirect household (Lal et al., 2009).

Sea-level rise is affecting agriculture in three different ways: Coastal erosion resulting in loss of land and some areas are permanently inundated, making it unsuitable for agriculture production. Some areas are also subjected to periodic inundation from extreme events, including high tides and storm waves, contaminating the fresh water lens, with devastating effects especially on atolls; and seepage of saline water through rivers during dry seasons, resulting in increasing the salt level in soils. Storm surges and increased salt water intrusion limits the range of crops that can be grown. The small atolls in particular face serious problems for example, pit and swamp cultivation of taro is particularly susceptible to changes in water quality. In Tuvalu, groundwater salinization as a result of sea-level rise is destroying the traditionally important swamp taro pit gardens (Webb, 2006) and raises concern on the safety of drinking water (Tekiene, 2000). In Kiribati, coastal erosion reduces crop productivity such as of pandanus varieties and coconut. The pandanus fruit is used by people as long term preserved food but most trees are lost through coastal erosion (GoK, 2007).

		Observed climate change and extreme events impact on crops and agriculture production
Group 1 Relatively larger countries of Melanesia	Papua New Guinea	Tuber formation in sweet potato was significantly reduced at temperatures above 34 °C (Allan & Bourke, 2009, NARI, 2011).
	Solomon Islands	Taro production has been reduced (less tubers and lower yields) in coastal areas over the years because of wave overtopping and warmer temperatures. Cyclone Namu wiped out rice industry in 1986 (GoSI, 2009)
	Fiji Islands	Drought and cyclones in 1997 led to a decline of production to 2.2 million tons of cane and 275 000 tons of sugar from a peak of 4.1 million tons of cane and 501 800 tons of sugar in 1986 (Gawander, 2007) .The cane growers' direct and indirect costs from the 2009 flood are estimated to be US$13.4 million. The costs include losses in cane output, non-cane and other farm losses, and direct and indirect household (Lal et al., 2009)
	Vanuatu	Increased temperatures and variability of rainfall resulted in increased pest activities with yams being the crop most affected and in livestock there was increased incidence of intestinal problems in cattle often associated with pasture. Some plants flowering earlier than usual while others are fruiting much later than normal during the past 3–4 years (FAO, 2008).
	New Caledonia	The estimated cost of damage to agriculture by Cyclone Erica in March 2003 was US$13 million (Terry et al., 2008)
Group 2 Middle – sized countries of Polynesia	Samoa	The increasing threats from new diseases and pests for both livestock and crops are linked to cyclones, flooding and drought and other variations in climate. The increasing incidence of forest fires has led to the destruction of crops as evident in the past forest fires in rural communities (GoS, 2005).
	Tonga	Squash crop which had been producing 50% of the country's exports by value was more than halved
Group 3 Resource poor micro, predominantly atoll, states	Federated States of Micronesia	Taro pits on some islands and atolls have been contaminated by salt water associated with a depletion of fresh-water lenses, extended droughts and saltwater inundation/intrusion (FAO,2008)
	Kiribati	The pandanus fruit is used by people as long term preserved food but most trees are lost through coastal erosion due to sea level rise and breadfruit and banana crops suffer from drought stress resulting in lower yields (GoK, 2007).
	Marshall Islands	During the El Niño season of 1997–1998, there was significant reductions in most crop yields (FAO, 2008)
	Palau	Taro pits on some islands and atolls have been contaminated by salt water associated with a depletion of fresh-water lenses, extended droughts and saltwater inundation/intrusion (Burns, W., 2000)
	Tuvalu	Groundwater salinization as a result of sea-level rise is destroying the traditionally important swamp taro pit gardens (Webb, 2007)

Table 4. Observed climate change impact on agriculture and crop production

6. Current climate change adaptation activities in agriculture

A number of regional climate change adaptation initiatives to address agriculture and crop production are currently implemented through regional organizations like the Secretariat of the Pacific Community (SPC) and the Secretariat for Pacific Regional Environment Programme (SPREP) and supported by various donors. They include:

1. The Regional Programme on Adaptation to Climate Change in the Pacific Island Region (ACCPIR) which initially has three pilot sites in Fiji, Tonga and Vanuatu but now is being extended to other PICs. Activities in Vanuatu include introducing climate-resistant crops, breeding extreme weather- adapted livestock, developing community land-use plans, trialing new agroforestry and soil stabilisation methods, and undertaking innovative climate adaptation education programmes whilst in Tonga, the focus has been on land and forest management on more vulnerable islands including Eua and Vava'u. The projected increase in temperature and rainfall show 'Eua having the highest soil productivity and soil erosion risk level compared to the other islands.
2. The Land Resources Division (LRD) of SPC is conducting atoll agriculture research and development at the Centre of Excellence for Atoll Agricultural Research and Development in Tarawa, Kiribati. Areas of work include atoll soil management, water management, cultivar evaluation, and improving the resilience of food production systems to climate change. The centre is also documenting sustainable food production systems, and food preservation and utilisation methods for atolls.
3. The Centre for Pacific Crops and Trees (CePaCT) and Forestry and Agriculture Diversification under the Land Resources Division (LRD) of the Secretariat of the Pacific Community (SPC) is the Pacific regional gene bank based in Fiji. It plays an important role in climate change adaptation efforts, improving food security and supporting domestic and export trade in agriculture and forestry products. Since 2009, it has distributed 4,038 plants to 12 PICs. The crops/species distributed include taro, sweet potato, yam, banana, breadfruit, *Alocasia, Xanthosoma*, , cassava, potato and vanilla. The LRD, with the support of the AusAID International Climate Change Adaptation Initiative (ICCAI) and the US government, has established a 'climateready' collection of crops and varieties known to have suitable traits at CePaCT. The collection is now being evaluated in individual PICs for climate tolerant traits such as resistance to drought, salinity and water-logging. The collection is a dynamic one and will be modified according to the evaluation information received. The ICCAI is also supporting a number of other activities, such as salinity tolerance screening research; agrobiodiversity studies in Fiji and Palau; and collaboration with CSIRO in crop modeling (SPC, 2010).
4. The Pacific Adaptation to Climate Change Project (PACC) is implemented by SPREP and is focusing on climate change adaptation. Its objective is to enhance the resilience of a number of key development sectors (food production and food security, water resources management, coastal zone, infrastructure etc.) in the Pacific islands to the adverse effects of climate change. This objective will be achieved by focusing on long-term planned adaptation response measures, strategies and policies.
5. The FAO with financial support from Italy is supporting fourteen island countries in the region in food security through the regional programme: Food Security and Sustainable Livelihood programme in the Pacific Island Countries (FSSLP). The over-

arching goal of the regional programme is to help island people grow healthier by eating more nutritious local foods, while reducing the amount of processed imported food they eat. Some of the crops promoted under the programme include drought and salt tolerance, pest and disease resistant varieties that are adaptable to changing climate (FAO, 2009).

6. The five least developed countries in the region including, Kiribati, Samoa, Solomon Islands, Tuvalu and Vanuatu have placed food security as an important issue to address in their National Adaptation Programme of Action (NAPA) to climate change and are now in the process of implementing national projects addressing various aspects of food security including crop production. Other PICTs are also developing their national adaptation plans and food security is high on their agenda.

7. Other factors contributing to the vulnerability of agriculture and crop production

Simatupang and Fleming (2001) identified three major factors that affect food security in the PICTs have negatively impacted agriculture and crop production. First, a change of diet amongst Pacific Islanders from locally produced food to imported food. Most imported food items such as rice, wheat, sugar, meat, eggs, milk, canned meat and fish, coffee, tea, alcohol and soft drinks are superior to roots and tubers in some aspects of cooking and serving practicality, shelf life, and also with respect to social prestige, which tempts the indigenous people to substitute these foods in their traditional diet. In Marshall Islands, production of taro and sweet potato has fallen dramatically because of increased access to imported staples which are more convenient for preparation and storage (FAO, 2008). Many of the imported foods are, however, nutritionally inferior to the more traditional ones. Second, expansion of large plantations and smallholder commercial farms pulls a large area of land, and potentially much labour, out of traditional food crop production, reducing its output. Third, increasing land pressure has pushed food gardens to less fertile and marginal steep lands and further away from homes. A number of households, especially in urban areas, do not have sufficient access to sufficient land for food gardening. In Tonga for example, there is now insufficient land for all commoner males to obtain their own plots and indeed some 30 percent of Tongans now do not own land. Other factors include: increased incidences of weeds, pests and diseases, thus necessitating increased application of pesticide and herbicides, which may lead to other unintended environmental impacts occurring both on the sprayed site, and offsite, especially water systems; loss of traditional farming techniques traditional knowledge; loss of plant genetic diversity and inbreeding of livestock and other domestic animals; invasive species; lack of sustainable land management; and lack of capacity to manage farm animals (FAO, 2008).

These are other clearly identifiable, non-climate change factors contributing to low crop production and reduced crop yields. These often interact with each other so that climate change exacerbates existing problems and subsequently affects food security in the region. In recognition of the impact of climate change and other factors discussed in this section, the PICT's have formulated a "Framework for Action on Food Security in the Pacific". The plan guides countries in determining relevant, specific country-level activity addressing food security. The framework for action was prepared in response to a call for action on food security from Pacific leaders at the 39th Pacific Islands Forum, held in Niue in 2008 (Food Secure Pacific, 2010). Some PICTs are now implementing the framework at national level to address the factors affecting agriculture and crop production mention here but these efforts are challenged by threat pose to crop production by climate change.

8. Tools and methods for assessment of climate change impact on crop production

As Allen and Bourke (2009) pointed out, climatic change is already influencing agriculture and food production in the PICs, but it remains difficult to predict the likely outcomes with certainty. This is because there is not enough information about changes in temperature and patterns of rainfall and rainfall extremes and furthermore agricultural responses to climate change will be complex. This together with limited capacity in the region to comprehensively assess the impacts of climate change and variability on the production of major pacific crops like cassava, taro, sweet potato, banana, rice and sugar cane add to this complexity.

Most estimates of the impacts of climate change on agricultural production in other regions of the world are done using crop simulation models. They are important tools for predicting the likely crop production scenario in the future. Although climate change is a growing concern for decision-makers in the region, information on the impacts of climate change is often lacking or incomplete. In agriculture, crop production will be affected by a combination of factors such as effects of changes in temperature and precipitation regime on plant physiology, changes on growing season onset and length, CO_2 fertilization effect, technological improvements, water and availability of which interactions are rather complicated. Researchers in the past two decades have been focused on predictions of climate change and its possible impact on agriculture and food supply in the next couple of decades. This is a major gap in the Pacific region.

A combination of integrated modeling from different disciplines and appropriate research is needed to advance the understanding and prioritization of the challenges climate change pose on agriculture and food production. Use of the crop simulation models like Decision Support System for Agro-Technology (DSSAT) and Agricultural Production Systems Simulator (APSIM) tools are starting to be used in research that will enable researchers to understand the agro-management practices most conducive to cope with the impacts of climate variability and change on important food and economic crops in the Pacific. The APSIM model is being used to determine climate change impact on cassava yield in Fiji and there is also plan to use DSATT on cassava, taro and sugar cane to predict impact of climate change on crop growth and adjust management practices to mitigate the potential impacts in some Pacific Island countries.

The Pacific Food Security Toolkit "Building Resilience to Climate Change – Root Crop and Fisheries Production" which was produced by the University of the South Pacific, Secretariat of the Pacific Community, Secretariat of the Pacific Regional Environment Program and Food and Agriculture Organization is an important document. It contains six modules that cover climate change, overview of key Pacific food systems, ecosystems and food securities, Pacific root crops, Pacific fisheries and additional tools to support Researchers, Academics, Farmers and all stakeholders.

9. Challenges and opportunities for food production

Some of the major challenges to agriculture and crop production in PICTs include: (1) increasing population against weak economic growth and rapid depletion of natural resources base with unsustainable development; (2) low level of awareness on climate change perceptions and competing government priorities; (3) limited capacity at all levels (regional, national and community) to develop and effectively implement adaptation measures; (4) inadequate resources and weak socio-economic conditions; and (5) unavailability and problem accessing reliable data on climate change impact on the sector in the region.

The agriculture sector has not been given priority in terms of resource allocation and development planning by regional countries in the past although it supports the majority of the people's livelihood. The vulnerability of the sector to climate change is beginning to be recognized amongst Pacific islands leaders and governments because of their concern for the regions food security (Barnet, 2008). The development of regional and national strategies on climate change and sustainable development frameworks now focus more on natural resources sectors including agriculture and food security. There is some level of commitment from the Pacific regional governments and their international partners to address climate change impact on agriculture and crop production. Through implementation of regional and national adaptation strategies to climate change there are opportunities to address issues and challenges in agriculture and crop production.

10. Conclusions

Observed climate data in the Pacific region is showing evidence that the climate is changing. The immediate or direct threat to agriculture and crop production comes from extreme events like cyclones, storms, flooding and drought. These extreme events are increasing in severity or intensity and frequency and already causing substantial damage to food crops and associated infrastructure or often result in total collapse of the PICTs economies, especially the small island countries. Recovery efforts are often negatively impacted by continuous occurrences of these extreme events, thus most PICTs are "locked" into a vulnerable situation.

The effects of climate change on crop production through increase in temperature, changing rainfall patterns, salt water intrusion are less immediate but also complex. Agriculture and crop production is under stress from these climatic factors but it remains difficult to predict the likely outcomes with certainty because of limited empirical data for the Pacific region. There is a need to continue to monitor the impact and conduct studies PICTs to equip for the future. Use of crop simulation models is one option to generate relevant information for planning adaptive measures to address food production and food security in the region. Because of PICTs continues exposure to extreme events and limited adaptive capacity, they also need assistance to develop and implement relevant adaptation strategies to climate change, especially in the agriculture sector where most people derive their livelihoods.

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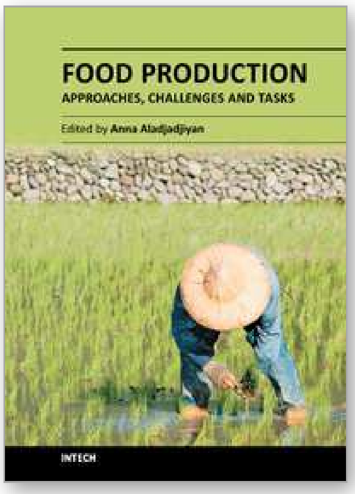

Food Production - Approaches, Challenges and Tasks

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This book is devoted to food production and the problems associated with the satisfaction of food needs in different parts of the world. The emerging food crisis calls for development of sustainable food production, and the quality and safety of the food produced should be guaranteed. The book contains thirteen chapters and is divided into two sections. The first section is related to social issues rising from food insufficiency in the third world countries, and is titled "Sustainable food production: Case studies". The case studies of semi-arid Africa, Caribbean and Jamaica, Burkina Faso, Nigeria, Pacific Islands, Mexico and Brazil are discussed. The second section, titled "Scientific Methods for Improving Food Quality and Safety", covers the methods for control and avoidance of food contaminants. Substitution of chemical treatment with physical, rapid analytical methods for control of contaminants, problems in animal husbandry related to diary production and hormones in food producing animals, approaches and tasks in maize and rice production are in the covered by 6 chapters in this section.