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Morgan Wairiu

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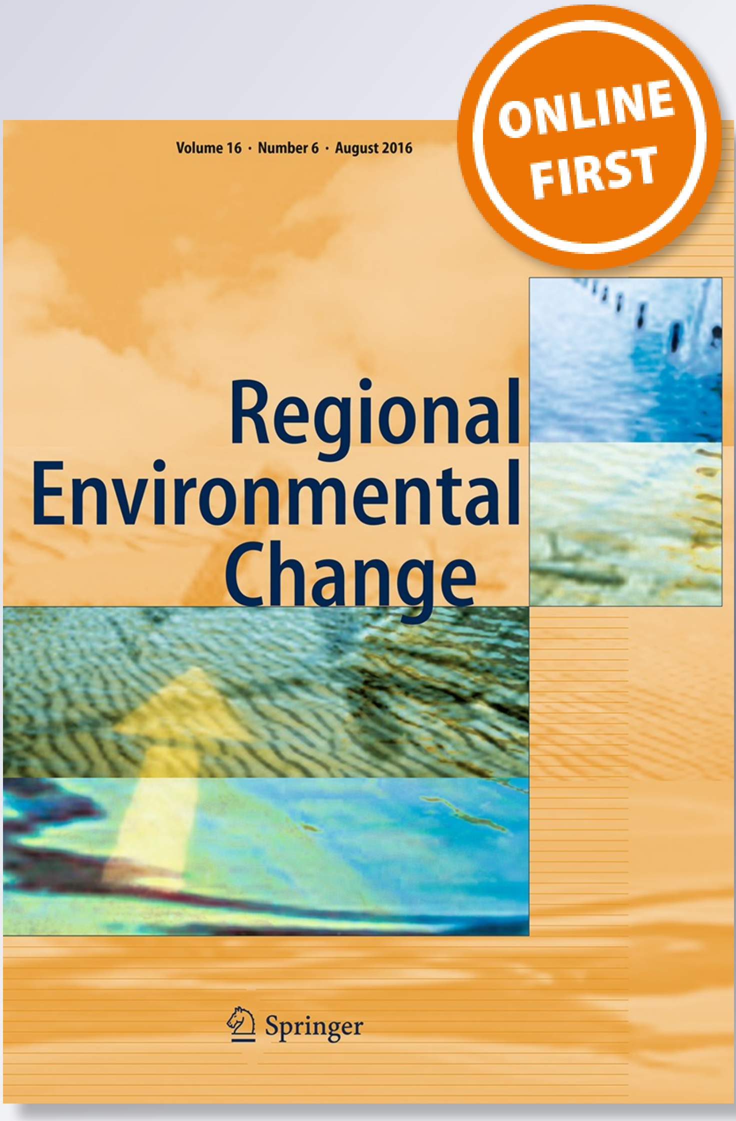

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REVIEW ARTICLE

Land degradation and sustainable land management practices in Pacific Island Countries

Morgan Wairiu[1]

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Abstract Land degradation in many Pacific Island Countries (PICs) has become an emerging concern in recent years. The causes of land degradation in PICs include: deforestation, inappropriate agricultural practices, overgrazing, mining, population pressure, land tenure issues and changing climate. Deforestation and inappropriate agricultural practices especially on sloping lands often lead to soil erosion, a key process leading to land degradation. On-site effects of accelerated soil erosion include decline in soil physical properties, loss of soil organic carbon and loss of plant nutrients and subsequently low crop productivity. This threatens the environment and food security for the growing population in PICs. The PICs are embarking on sustainable land management practices to address land degradation and safeguard the resource for their future generation. However, limited resources, lack of capacity and awareness on land degradation amongst the population are serious obstacles to implementation of sustainable land use plans and management.

Keywords Land degradation · Deforestation · Soil erosion · Sustainable land management · Pacific Island Countries

✉ Morgan Wairiu
wairiu_m@usp.ac.fj

[1] Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Laucala Campus, Suva, Fiji

Introduction

The total land area in the Pacific Island Countries (PICs) is only around 500,000 km^2 while they are spread over almost 20 million km^2 of ocean. Thus, only less than two per cent of Pacific islands region is land, while the rest is ocean. The island countries vary significantly in size, from Papua New Guinea with land area of 460,330 km^2 to Nauru and Tuvalu that are smaller than 30 km^2. The region hosts a population of approximately 9 million, a number expected to rapidly increase by 2030 (FAO 2008). The majority of the population lives in rural areas and relies heavily on agriculture, forestry and fisheries as a source of food security. For centuries, the traditional Pacific Island agricultural systems have been highly sustainable even while these included cropping on sloping lands. However, these systems are now seemed to be breaking down which could have major implications for sustainable food security. Currently, population pressure, deforestation through large-scale agriculture using poor agricultural practices, commercial logging, mining, land tenure issues and changing climate have been identified as major factors responsible for increasing rates of land degradation across the islands in the region. Land degradation is a major concern to the Pacific countries. In most countries, farming on steep slopes continues to cause serious soil erosion problems in traditional cropping area and these lands are now far more vulnerable to the adverse effects of excessive rainfall or prolonged drought spells than in the past. Climate change which includes extended periods of drought and intense rainfall will exacerbate the problem in coming decades and beyond.

This paper discusses status of land degradation in PICs with emphasis on soil erosion as a major process leading to land degradation and identifies sustainable land management strategies and practices being employed by island countries to address and avoid land degradation.

Land degradation

Land comprises of soil, water and associated plants and animals. FAO/UNEP (1995) defines land degradation as reduction in land productivity that affects the integrity of an ecosystem through process such as erosion, salinization and loss of soil fertility. These processes are accelerated through activities like deforestation, overgrazing, intensive agriculture and urbanisation. About 18.1 million km^2 or 92 % of total degraded land worldwide resulted from inappropriate agriculture practices and large-scale conversion of land for agricultural activities and other industrial uses. These include: 6.8 million km^2 of degraded land by overgrazing, 5.8 km^2 through deforestation due to logging and agricultural production and 5.5 million km^2 degraded land through inappropriate farming practices (as a result of wind and water erosion; salinization and water logging; and soil nutrient loss). Land degradation caused by other factors include: 1.37 million km^2 from fuel wood harvest and 0.195 million km^2 degraded by industry and urbanization (FAO/UNEP 1995).

Causes of land degradation in PICs

Direct causes

The direct causes of land degradation amongst PICs include (1) deforestation; (2) inappropriate farming practices; (3) overgrazing by livestock; (4) mining; and (5) urban development, while the indirect causes include (6) population pressure; (7) land tenure; and (8) climate change. These factors are discussed in more detail in the subsequent sections.

Deforestation

Deforestation is taking place through unsustainable commercial logging and land clearing for commercial agriculture. These activities are happening over large tracts of natural forest in most high Island countries in Melanesia including: Papua New Guinea (PNG), Solomon Islands, Fiji and Vanuatu and to a lesser extent in Polynesian countries like Samoa and Tonga. Land clearing often results in soil compaction and exposes land to soil erosion. In Fiji, about 140,000 ha of forested land has been converted to non-forest land uses since 1967 and resulted in more degraded land (GoF 2007). In Solomon Islands, almost 10,000 ha of natural forest was logged using heavy extraction machinery in the last decade (FAO 2010). Destruction of primary forest using extraction machinery is shown in Fig. 1.

In Samoa, land clearing for agriculture use is the most serious cause of land degradation; an estimated 4000 ha of forest land are being cleared primarily for agriculture annually. About 87 % of land area in Samoa is being used under crops and 4.7 % under livestock. Land under non-agricultural use has diminished to just 3.4 % from 17 % in 1989 (GoS 2007). In small island countries, the impact of cyclones often contributed more to deforestation than clearing for agriculture and logging. For example in Niue, cyclone Heta in early 2004, uprooted 20 % of the trees and some 60 % suffered breakages and defoliation as a result of the sea spray (GoN 2004).

Inappropriate farming practices

Inappropriate farming practices like cultivation of marginal sloping lands has resulted in erosion, loss of soil fertility, decline in crop yield, sedimentation of water and coastal systems in most PICs. The GoF (2007) reported that intensive use of marginal steep land areas in Fiji leads to shorter fallow periods and ultimately to soil degradation and reduced yields of sugar cane, ginger and taro crops. The small size of farm holdings (60 % are less than 3 ha) forces farmers into intensive cultivation (often monocropping) for high-output, short-term production without or with only minimal fallow periods. Enforcement of the land use policy has not been effective given the lack of understanding and coordination between key stakeholders on the importance of conservation (GoF 2014a). In Niue, about 80 % of all households use bulldozer to clear land and this mechanized clearing method has resulted in damage to soil structure and a reduction in fallow period of 5–8 years and reliance on herbicides/fertilizers to maintain and increase taro production levels for export has seen a further reduction in fallow period to 3 years (GoN 2004). Tuvalu experiences similar problem with use of fertilizers and pesticides to enhance agricultural productivity. While higher crop yields have been gained, overuse of chemicals has caused land to become degraded through changes in the physical and biochemical composition of the soil. Consequently, farmers have abandoned their land and moved to new locations for their sustained livelihood through crops productivity (GoT 2006). The same problem is also experienced in Tonga, where intensive mechanical cultivation, heavy fertilizer and pesticide use coupled with excessive clearance of coconut and trees has significantly affected the country's land resources (GoT 2002). The drive to increase productivity on land has typically led to an intensification of cultivation on existing farmland, and the extension of cultivation onto previously unused and/or forested and

Fig. 1 Destruction of primary forest using extraction machinery in Solomon Islands

marginal land in the PICs. Examples of intensified modern farming practices are evident throughout all PICs and include coffee in PNG, taro in Fiji, vanilla and kava in Tonga, and past surges of squash production in Tonga and Vanuatu (FAO 2008).

Overgrazing

Overgrazing is livestock farming without good pasture management and overstocking which result in bare patches and leads to soil erosion, especially on steep marginal areas. This has become evident in recent years in livestock farms in Fiji, Samoa, Solomon Islands and Vanuatu. For example in Fiji, goat grazing areas are invariably overstocked and show bare eroded patches due to typical farmer's need to recoup expenses as quickly as possible and an ignorance of controlled grazing techniques (GoF 2006). It was also observed amongst small holder livestock farmers in Samoa (GoS 2007) and Solomon Islands (GoSI 2006). In Vanuatu, deterioration in land quality was exacerbated by the commercialization of livestock farming without good pasture management, with unfenced paddocks, no protection of riparian zones and overstocking (GoV 2007b).

Mining

Mining causes land degradation through extensive land clearing and when land is exposed it is prone to erosion. In Solomon Islands, the Gold Ridge Mining Limited (GRML) has cleared a large tract of natural forest for its open-cut mine and its associated earth work like roads is resulting in excessive run-off and sedimentation in river systems (GoSI 2006). This situation is more pronounced in PNG where they have more than a dozen open-cut mines which involved clearance of large tract of natural forest (GoPNG 2006). In Fiji, the environmental impact survey of the Mount Kasi open-cut gold mine indicated significant ramifications for the surrounding environment, Yanawai River and coral reef ecosystems. The mine is at Savusavu, near the Yanawai River on the southern coast of Vanua Levu, Fiji's second-largest island. It ceased operation in 1998. The long-term impact of the mining works, especially where mine tailings are deposited and other environmental effects will have long-term consequences (GoF 2006). In Vanuatu, the expansion of mining operations for aggregate for construction is a major and growing issue surrounding the urban areas of Port Vila and Luganville (GoV 2007b). The areas cleared for mining always remain exposed resulting in run-off and degraded soils.

Urban development

Urban development is increasing and most arable lands are now brought into development such as housing, garment industries, tourism and others in most PICs. For example, about 500 ha of first-class sugar cane land in the corridor between Nadi Town and Nadi Airport in Fiji has been taken for non-agricultural purposes (GoF 2007), and best agricultural land at Lunga on the Guadalcanal plains in Solomon Islands has been converted to residential and commercial plots (GoSI 2006). In most PICs, urban development like hotels, housing, ports, airports, highways and roads has taken up prime arable lands and food production has been pushed back onto marginal lands where indiscriminate land cultivation often resulted in land degradation. In Tuvalu, incorrect use of sea walls and boat ramps, removal of sand and aggregates for construction purposes and tree felling along the shoreline is causing severe erosion. The sea walls have exacerbated coastal erosion under extreme events like cyclones (GoT 2006). In Cook Islands, tourism infrastructure development has concentrated on the foreshore and about 64 % of the foreshore's problems are to do with the construction of tourist facilities and the protection of properties. Building too close to the sea, completely clearing natural vegetation and the replacing it with ornamental species not well suited to the environment as well as the disposal of liquid waste are three issues associated with tourism development that are contributing greatly to growing land degradation problems in the Cook Islands (GoCI 2004).

Land tenure

Availability of land for agriculture and other commercial activities is subjected to land ownership and those that do not have secured land tenure often abuse land and often results in land degradation. For example, in Fiji, land leases issued under the native and crown land through the Agriculture Landlord's Tenants Act are not conducive to the sustainable land resources management, where the lessee tend to mine the land for economic gains, knowing very well that the lease will expire after 30 years of occupation and such action often resulted in high degree of land degradation (GoF 2007). In Cook Islands, many people own lands which are parcelled in small areas where individual owners developed them and activities of one landowner affect the next owner. This has created degradation along the foreshore or coastal ridges. Reclaiming of the wetlands also affected the drainage network that drains the sloping lands and watershed areas and the low-lying areas behind the coastal ridges; as well as the erosion of sloping lands thereby causing drainage blockages in streams and stream mouths (GoCI 2004).

Indirect causes

The direct causes of land degradation are strongly linked to the indirect causes or the main drivers such as: (1) The increasing population pressure of the Pacific Island Countries; (2) The increasing economic drive for export and import substitution; and (3) The increasing impacts of climate change. Addressing these indirect causes, it will define the way forward to solving the land degradation issues.

Population pressure

The increasing population is exerting pressure on land and is causing land degradation. The pressure from the increasing population on land resources is mainly on two fronts: first, the pressure of food production and second, the increasing economic drive for commercial production for export and import substitution. In Solomon Islands, extended cropping periods on the same piece of land and reduced fallow periods resulted in reduction of soil fertility, with consequent reduction in crop yields (Bourke et al. 2005). The same is also experienced in Samoa (GoS 2007). In Vanuatu, the fallow periods are being shortened from 10 years to less than 5 years as population pressure on land grows. This has contributed to a significant rise in soil degradation (GoV 2007a).

In the case of increasing economic drive for commercial production for export and import substitution, it was observed in Fiji that competition and pressure for land through population growth and expansion of cash cropping and grazing on the flatter lands, subsistence gardens are forced onto steeper slopes. Some gardens experience soil loss, especially when traditional mulching is not practised and fallow periods are too short. Soil loss measurements clearly demonstrate that the agricultural productive base in many sugar cane areas, and with ginger on slopes, is declining at a rate that is well above what would be regarded as economically acceptable (GoF 2007). The same was also observed for coffee production and in Papua New Guinea and squash cultivation in Tonga.

Economic drive for export and import substitution

In the PICs, traditional cropping systems are based on long bush-fallow system to maintain soil fertility and in the case of atolls, it involves recycling of large amounts of organic material in pits or heaps. However, smallholders who have intensified crop production to supply growing urban and export markets have typically failed to replenish soil nutrients and organic matter adequately which leads to falling yields and problems with soil-borne diseases that characterize declining soil health (ACIAR 2014). The commercial production of taro in Fiji and Samoa, ginger in Fiji, kava on the sloping lands of Fiji and the FSM, and squash in Tonga, has generally resulted in increased soil erosion, reduced yields and decreased household food security (SPC 2014). In PNG, the total value added created by agriculture makes up a high percentage (36 %) of GDP with exports in 2011 equivalent to USD 1.28 billion; nearly six times that of Fiji. In recent years, Vanuatu's agricultural products have made up around 80 % of total export earnings; by far the highest of any Pacific Island Country (Taylor et al. 2016).

Climate change impacts

Climate change can negatively impact land leading to land degradation. These include increasing temperature within the soil profile, changing rainfall patterns, sea level rise which results in coastal erosion, inundation and salt intrusion, and increasing intensity of extreme events such as cyclones and droughts. For example, in Kiribati, most pandanus trees are lost through excessive coastal erosion due to salt water inundation and sea level rise and breadfruit and banana crops suffer from drought stress resulting in lower yields (GoK 2007), while in Tuvalu, groundwater salinization as a result of sea level rise is destroying the traditionally important swamp taro pit gardens (Webb 2007), as shown in Fig. 2.

The World Bank (2006) reported that during the period 1950–2004, about 207 extreme events were recorded in the Pacific region, and the cost of climate-related disasters on the agricultural lands and 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. In Fiji, the 1997 and 1998 drought events resulted in 50 per cent loss in sugar cane production and total losses in the industry were around US$50 million, while other agriculture damage and losses including livestock death and damage to fertile land amounted to around US$7 million (McKenzie et al. 2005).

The frequency and intensity of ENSO (El Nino and La Nina) events and the accompanying extreme events such as extreme rainfall, floods, tropical cyclones and droughts are posing great threat to land resources. For example in Tuvalu, the vulnerability of swamp taro to dry conditions was particularly highlighted and salinity problems were exacerbated illustrating the effect of multiple climate-related stresses. The combination of the high temperatures experienced during the drought and the increasing salinity of the pulaka pits adversely affected the growth of the swamp taro. The 2013 drought in Republic of Marshall Islands was reported to have affected bananas growing in home gardens (Taylor et al. 2016).

Soil erosion in PICs

Accelerated soil erosion through deforestation and inappropriate agriculture practices especially on sloping lands is recognized as major process leading to land degradation and threat to crop productivity in the PICs. The effects of erosion include decreased productivity, sediment deposition in rivers through run-off with subsequent increase in flooding and damage to coastal ecosystems. Degraded soils have low soil fertility and starve plants of proper nutrition, resulting in poor crop yield (PAFPNet 2010).

Fig. 2 Groundwater salinization destroying the traditionally important swamp taro pit gardens in Kiribati

Principal processes that lead to decline in crop yield due to erosion include: (1) reduction in effective rooting depth (loss of topsoil), (2) loss of plant nutrients and soil organic carbon (SOC), (3) loss of available soil moisture and water holding capacity, (4) loss of land area and (5) damage to seedlings (Lal 1998).

Despite the large volume of literature on soil erosion on a global basis, there are little data on soil erosion and its impact on soil quality and crop productivity in PICs. It has been reported (GoPNG 2006) that about 58 per cent of the total agricultural land area in PNG is subjected to soil erosion. In Fiji, erosion index (EI) was reported to be very high, about 700 for the dry zone and 800 for wet zone which is high by world standards where EIs average between 200 and 400 (GoF 2006). The erosion index (also called the erodibility index) is a numerical measure of the potential of a soil to erode, considering climatic factors and the physical and chemical properties of the soil (NRCS 2010). The higher the index, the greater is the investment needed to maintain the sustainability of the soil resource. In 1998, a Japanese International Corporation Agency (JICA) study team reported the annual soil loss amounts from four different watersheds in Fiji, namely, Rewa 32.2 Mg/ha; Ba 69 Mg/ha; Nadi 81.4 Mg/ha; and Sigatoka 76.9 Mg/ha (GoF 2006). To contextualize this amount of soil loss, consider the top 10 cm of 1 ha of soil. This has a volume of $100\ \text{m} \times 100\ \text{m} \times 0.1\ \text{m} = 1000\ \text{m}^3$. At a typical soil density of $1500\ \text{kg/m}^3 = 1.5\ \text{t/m}^3$, this volume of soil has a mass of 1500 t. Therefore, an erosion rate of 100 t/ha/year implies that on average the top 10 cm of soil would be eroded away in 15 years. In practice of course, erosion is usually uneven, so it is more likely that 20 cm would be eroded from half of a 1-ha plot and very little from the rest.

Severe soil erosion on the island of Aneityum (Vanuatu) has contributed to the dying of coral reefs in recent years. This is attributed to intensive logging operations and burning of grasslands on uplands of the island (GoV 2007a). In Solomon Islands, soil erosion has long been recognized as a major problem by several researchers (Hansell and Wall 1970; Webb 1974; Wall et al. 1979; Stephens et al. 1986; and Eyles 1987). Hansell and Wall (1970) identified Kaichui and Itiri mountainous land regions on Guadalcanal Island as subjected to moderate to severe erosion. Webb (1974) reported that in excess of 15 % of land had been significantly damaged by machine logging operations on the island of Kolombangara and pointed out that steep portions of these logged areas can be very prone to soil erosion. Eyles (1987) also observed that logging on steep lands significantly increases the sediment run-off for 1–2 years before complete establishment of ground cover on Kolombangara Island. During cyclonic rainfall events, mountain regions can be susceptible to landslide erosion as observed during cyclone Namu in 1986 on Guadalcanal (Stephens et al. 1986). Other studies on soil erosion in the PICs include those by Morrison (1981), Liedtke (1984), and Clark and Morrison (1987), and Liedtke (1988) in Fiji; Williams et al. (1981), Wood (1984), Humphreys (1984), Oldfield et al. (1985), Carman (1989), Humpreys and Wayi (1990), Sillitoe (1993), and Konabe (1996) in Papua New Guinea (PNG), and Pratap (1994) in Samoa. Reported soil erosion rates in these studies generally range from 10 to 300 Mg/ha/per year as shown in Table 1.

It may be reported here that most of the soil erosion rates reported as above have been based on the Universal Soil Loss Equation (USLE) without any calibration for the Pacific region. They cannot be, therefore, considered to be truly quantitative; however, they do indicate the potential risk of soil erosion.

The only quantitative data on soil erosion came from run-off plot studies that included those by Liedtke (1988) in Fiji and Humpreys and Wayi (1990) in PNG. T he PACIFICLAND soil management network set up soil erosion studies to quantify soil loss from sloping lands under the current farming practices in the South Pacific region in the 1990s. The soil loss amount obtained through this study is shown in Table 2.

It is evident from Table 2 that, in general, soil loss reported is found to range from 7.2 to 36.1 Mg/ha. The site at Samoa recorded unusually low amount of just 0.2 Mg/ha. For the Fiji site, repeated measurement after several years resulted in soil loss rate of 50 Mg/ha per year on ginger plots where no conservation is practised. This is high compared to the soil loss index in the tropics of 13.5 Mg/ha per year. But, interestingly in those ginger plots where the low-cost sustainable land management technologies such as vetiver grass as hedge rows were used, soil loss was less than 1 Mg/ha per year (GoF 2007). Soil loss measurements in Fiji clearly demonstrate that the agricultural productive base in many sugar cane areas, and with ginger on slopes, is degrading (Leslie and Ratukalou 2002).

Soil erosion often leads to land degradation through direct effect on soil properties such as reduction in topsoil depth, loss of soil organic carbon (SOC) and changes in soil physical and chemical properties.

Soil erosion effect on crop productivity

Soil erosion is one of the major causes of declining crop yield on sloping lands in the Pacific region (Howlett 1996). On-site effects of accelerated soil erosion on crop productivity are decline in soil physical properties and loss of plant nutrients. The soil physical properties included structure, bulk density, infiltration rate, available water holding capacity and favourable rooting depth (Olson et al. 1999). While other factors such as weather and genetic

Table 1 Soil loss rates in some Pacific Island Countries

Location	Slope (%)	Time (months)	Soil loss rate (Mg/ha/year)[a]	References
Fiji (Waibau)	–	1.1	59–65	Liedtke (1988)
Fiji (Waibau)	–	1.1	60–66	Liedtke (1988)
Fiji (Seaqaqa)	9–14	–	300	Clark and Morrison (1987)
Fiji (Nadi)	33–41	–	90	Clark and Morrison (1987)
Fiji (Lautoka)	–	–	24–80	Clark and Morrison (1990)
Fiji (Lautoka)	9–23	1	69–78	Liedtke (1984)
Fiji (Nadi)	26	–	37	Morrison (1981)
Fiji (Nausori)	26	–	86	Morrison (1981)
PNG (Chimbu)	–	–	25	Silitoe (1993)
PNG (Chimbu)	40–45	7–15	40–80	Humpreys and Wayi (1990)
PNG (Chimbu)	45	7–15	10	Humphreys and Wayi (1990)
PNG (Rabaul)	–	–	38.2	Carman (1989)
PNG (Chimbu)	–	15–18	80	Humphreys (1984)
PNG (Tari)	–	1.3	13.6	Wood (1984)
PNG (Bubia)	–	3	10–12	Williams et al. (1981)
Tahiti	–	–	15	Eyles (1987)

[a] 1 Mg = 1000 kg = 1 tonne

PNG Papua New Guinea

Table 2 Soil loss under farmers practice in countries participating in the PACIFICLAND soil erosion network *Source*: Howllet 1995

Country	Location	Treatment	Rainfall (mm)	Slope (%)	Time (months)	Soil loss (Mg/ha)
Fiji	Waibau	Farmers practice	4000	27–32	41	10.0
Papua New Guinea	Aiyura	Farmers practice	2500	18–36	12	28.0
Vanuatu	Lakura	Farmers practice	1962	18–36	32	36.1
Vanuatu	Sara	Farmers practice	3486	34–45	20	7.2
Western Samoa	Tapatapao	Farmers practice	4500	36–47	13	0.2

potential can control the overall production of crops in a geographical area, Olson et al. (1999) pointed out that the soil system remains the major determinant of yields because of the environment it provides for root growth.

El-Swaify and Cooley (1981) reported that a major factor that can cause reduced productivity is the physical degradation of the soil within the rooting zone. They monitored soil deposition as a result of erosion in Hawaii and found that aggregates less than 2 mm size and soil particles were mainly transported in the fast-flowing water and re-deposited on flat areas. The detachment and transport of the soil aggregates from steeper slopes resulted in reduced topsoil depth and caused reduction in infiltration rate to 1.23 cm/h on the slopes. El-Swaify and Dangler (1982) also observed that soil erosion led to loss of organic matter and soil nutrients and subsequently a reduction in productivity.

Crop productivity is defined as the biophysical production or output (biomass or grain yield) per hectare and this may change due to change in soil properties over time (erosion, compaction, salinization, water logging, etc.), introduction of new cultivars and change in inputs used (Lal 1998). El-Swaify (1993) reported that erosion impacts on crop productivity of highly weathered tropical soils are more severe than for temperate soils. According to Lal (1995), one of the reasons why there has not been enough work in this area even in other ecoregions of the world is that it is very difficult to conduct experiments that assess soil quality and directly relate it to crop productivity. The difficulty is because productivity or yield is not a function of soil quality alone but other factors such as prevalent climate, incidence of pest and diseases, cultural practices and past and current erosion also interact and affect productivity. Therefore, assessment of the soil quality is important to planning strategies for sustainable land use and management.

Addressing land degradation

The PICs now recognize that land degradation is a threat to future food security of their growing population. However, there is little information on the extent of land degradation and its impact on crop productivity and the environment in the region. This makes planning for relevant and appropriate interventions that address land degradation difficult. In recognition of the impacts of land degradation on the people's livelihood and environment, the PICs have signed on and ratified the United Nations Convention to Combat Desertification (UNCCD). As parties, the 14 PICs are being supported under the UNCCD to implement National Sustainable Land Management Projects. One component of the project is the development of National Action Programmes (NAP) to combat land degradation and mitigate the effects of droughts. The NAPs are developed as the main tool for addressing land degradation at the national level. The NAPs promote SLM which is defined as the use of land resources such as soils, forests, rangelands, water, animals and plants for the production of goods and services to meet changing human needs while assuring the long-term productive potential of these resources and the maintenance of their environmental functions. The SLM is also crucial for building up the resilience of ecosystems and for cushioning the vulnerable from the negative impacts of climate change.

Developments of NAP by PICs are currently progressing at various stages through wider stakeholder consultation at all levels and will address the underlying biophysical and socio-economic causes of land degradation in a participatory, integrated and coordinated manner and promote the active participation of resource owners and land users (SPC 2008). Five countries: Samoa, Fiji, Palau, Niue and Tuvalu have completed their NAPs. In parallel to the development of the NAPs was an approach for capacity development for farmers, agriculture extension, NGO's and integration of SLM in relevant sector development plans. A number of farmers are now pursuing SLM practices in Fiji, Tonga and Vanuatu (UNDP 2013). While the process involved stakeholder consultation and capacity development at all levels, it was top–down and project driven. The effective implementation of the NAPs is depended on ownership and leadership from network of farmers or communities, the type of technologies identified and available resources. The missing link is strong coordination with farmers at local level for farmers to build and strengthen their networks to support SLM.

At a regional level, the Secretariat of the Pacific Community (SPC) established the Land Management and Resources Support Centre in 2005 within its Land Resources Division (LRD) to support land use policy development and planning in PICs. The LRD has established an information network that provides biophysical, agricultural, forestry, economic and land use information on all PICs. A Land Resources Working Group (LRWG) was constituted in 2008 with objectives to progressively work towards an integrated approach to land resource management; share information; and raise the profile of land resources management and community level activities in the PICs (SPC 2008). Lack of existing or up-to-date information on an integrated approach towards SLM and the management of natural resources are common across all PICs. The SPC is also supporting information sharing amongst LRWG agencies and streamline information dissemination through its information network, the Pacific Agricultural and Forestry Policy Network (PAFPNet 2010). Mainstreaming SLM principles into National Sustainable Development Plans (NSDPs) is also important.

At national level, some countries also developing national policies and strategies on SLM, for example in PNG, the SLM is available through the current government's medium term plan or the Medium Term Development Strategy (MIDS) 2005–2010 (GoPNG 2006). It demonstrates the governments' commitment to achieve sustainable land management and combat land degradation. The national goal for agriculture in Fiji is to build sustainable community (GoF 2014a, b). This underlying goal or purpose is to establish a diversified and economically and environmentally sustainable agriculture economy in Fiji. The Land Resources Division of SPC has also published a reference manual for utilizing and managing soil resources in Fiji (Leslie 2012). The manual provides a broad framework for understanding and interpreting the soil resources of Fiji in bringing together into one document all the relevant available soil data. It describes these data in a user-friendly format designed for use by farmers, institutional extensionists, researchers, agribusiness managers and land use planners. Samoa has also developed a similar manual which provides the mapping of soil types and identification of potential locations in optimizing use of the arable land available for agriculture. The Government has taken the initiative of developing the strategic planning framework for the longer-term development of agriculture with a focus on land use and sustainable land management (GoS 2011).

Sustainable land management practices

The NAPs identify SLM as a tool to addressing land degradation. To achieve sustainable outcomes in SLM, it should be introduced at both the national and local level. Leslie and Ratukalou (2002) suggested use of landcare group concept which is based on participatory land management and community development. The SLM approach involves both the long-term maintenance of the productive capacity of agricultural lands, and the sustainable use of natural ecosystems thus emphasis be placed on institutional strengthening, local decision-making and building the self-reliance of local communities. National demonstration sites

Fig. 3 Alley cropping system using *Gliricidia sepium* legume as hedgerow, example of sustainable land management practice in Vanuatu

were set up participatory land management programs to showcase best methods to address land degradation and promote SLM to local communities in Fiji, Samoa and Kiribati. For example, 18 conservation demonstration sites were set up in Fiji which provided "hands on" experience and training for villagers on SLM work.

To enhance adoption of SLM and other techniques to reduce land degradation, the PIC governments need to develop an institutional capability for integrated land use planning. Such an institute of authority should have the support of the rural people and for farmers to take active role, ownership and leadership land use planning and SLM practices. Some of SLM practices may include: sustainable forestry management; agroforestry; alley cropping using live hedges on slopes; minimal biomass waste burning; and using organic manures and legumes to fix atmospheric nitrogen. These practices can reduce deforestation, control soil erosion, especially on sloping lands and maintain soil fertility. Figure 3 shows alley cropping using the legume *Gliricidia sepium* a hedgerow.

Research to improve soil health started in 2011 by SPC in Fiji, Samoa and Kiribati. It is part of the countries commitment to sustainable use and development of their natural resources and ecological processes. The project is implemented in collaboration with the Australian Centre for International Agricultural Research and the Fiji, Samoa and Kiribati departments of Agriculture. Technical assistance is provided by the Queensland Department of Agriculture, Fisheries and Forestry. Current research is under the Australian Government taro rehabilitation project and the Food and Agriculture Organization of the United Nations (FAO) Technical Cooperation Programme's mucuna trials.

The initial findings suggest that increasing the organic matter content improves the soil, moving towards restoring all dimensions of the soil functions. Increased soil organic content also increases the quantity of carbon in the below-ground carbon pool (SPC 2014). Results from field trials showed a generally a positive effect of lime, and Mucuna has been shown to improve taro yield and decrease losses due to soil-borne pathogens. Data collected from farmers from Taveuni Island in Fiji also provided further incentive for farmers to incorporate a fallow in the taro farming system. In Kiribati, the project has demonstrated in South Tarawa and in Abaiang that sweet potato varieties can be successfully grown with compost. The yield can even be much better if critical agronomic practices like mounding and lifting of vines is taught to growers (ACIAR 2015). The farmers are adopting the use of Mucuna legume and lime because they are yielding results.

Based on the success of the demonstration sites, the Fiji Government has put in place national budget allocation for SLM since 2013. In Tonga, demonstration plots were established in three regions using legume for soil improvement and coastal mangrove planting to prevent coastal erosion. The approaches have been taken up by the farmers and local communities (UNDP 2013). Maintaining soil health as production systems is recognized across the region as a key issue in ensuring sustainability (ACIAR 2014).

During 2013–2014, SPC published three manuals (on soils, crop margins and crop suitability maps) for Fiji. These manuals are currently being used by the Ministry of Agriculture to improve land use management. At the same time, SPC is supporting agroforestry demonstration farms in Fiji to exhibit good land management on sloping plots (SPC 2014).

The over exploitation of forest for timber through logging and shifting cultivation is major drivers of deforestation. To reduce the current rate of deforestation, use of sustainable land management tools such as forest management and agroforestry using alley cropping on sloping lands is important. Poor logging practices affect the ability of forest to regenerate and use of heavy machineries caused soil compaction and topsoil removal which often result in soil erosion and sedimentation of river systems. Sustainable harvesting through forest management is a basic management tool that can be used instead of logging using heavy machines. In Fiji and Samoa, agroforestry practices with alley cropping are been promoted amongst famers. The GoF (2007) reported that live hedge row technologies are being assessed against the farmer's current practices. They include vetiver grass strips, pineapple hedgerows and other crops such as kava or leguminous tree species that were selected by both the researchers and farmers. It was observed that soil loss rate on a ginger plot where no conservation is practised yielded more than 50 Mg ha^{-1} -year^{-1} compared to ginger plot with vetiver grass as hedge rows where it yielded soil loss of less than one 1 Mg/ha per year. Investigations are also being carried out on legume tree species *Erythrina subumbrans*, a soil fertility improvement species on acid soils of the uplands of Fiji. Surveys of traditional agroforestry practices in Fiji are also carried out and documented to provide a range of technologies that could be adapted to meet the conservation and economic needs of the people. To promote leguminous and nitrogen-fixing tree species such as *E. subumbrans* and *G. sepium* on contours to act as living barriers, nutrient input has also been given. Since 2007, about 300 farmers have adopted the low-cost sustainable land management technologies all over Fiji.

Opportunities to adoption of proven successful practices in the Pacific region include: (1) building on existing farmer technologies that are low cost and less labour intensive; (2) farmers direct involvement and participation in planning and implementation of farming practices; (2) when the technology yields positive results or tangible benefits to the farmers. This is similar to lessons learnt through other landcare initiatives in Australia and other regions like in Africa and Asia (Catacutan et al. 2009). In the case of Fiji, farmers were involved from the planning to the implementation stages of the SLM process through participatory approach. Community level governance guiding sustainable resources has been strengthened and people empowered to plan and manage use of their resources.

The impediments for the adoption of proven successful practices are dependent on the type of cropping system. For example in Solomon Islands and Papua New Guinea, the adoption of contour farming using shrub legumes was low, primarily because the technology required intensive labour and planting materials not usually available and affordable by the local farmers. Further most local farmers are still practicing shifting cultivation and moving onto new areas or areas previously under fallow.

Conclusion

Land degradation is recognized by PICs as a threat to food security and ecosystem services for Pacific Community. The major causes include: deforestation through large-scale agriculture using poor agricultural practices, commercial logging, mining, pollution, land tenure issues and changing climate. One of the processes leading to land degradation caused by poor agriculture practices is soil erosion. Sustainable forest management tools and use of agroforestry practices such as alley cropping are some technologies that PICs can use to address land degradation. These are appropriate and low-cost technologies that directly address deforestation and soil erosion. Use of organic manures and legumes to fix atmospheric nitrogen to maintain soil fertility is more sustainable and environmentally healthy than use of chemical fertilizers and pesticides. Limited data and lack of awareness on land degradation amongst the population in PICs are obstacles to implementation of the sustainable land management practices in the region. There is a need for more assessment on the extent and severity of land degradation and impact on crop production.

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