Innovative agricultural intensification to cope with demographic and climatic changes for subsistence producers

– a case study of Sandfly Island, Solomon Islands

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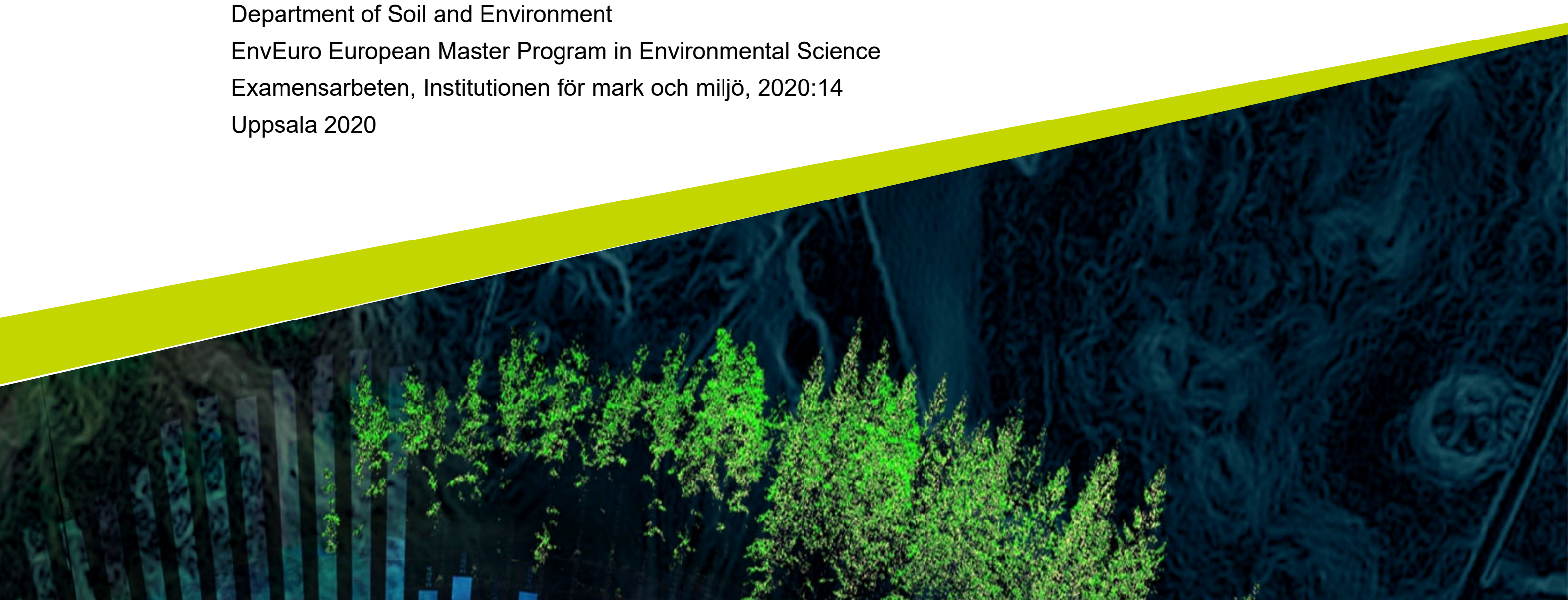

Innovative agricultural intensification to cope with demographic and climatic changes for subsistence producers – a case study of Sandfly Island, Solomon Islands

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Abstract

This research aims to study the dynamics of agricultural intensification amongst the small island community of Sandfly Island, Solomon Islands, and to observe the spreading of new agricultural practices of intensification that can help mitigate the pressures of climate change on the one side; and on the other side of a growing food demand from a growing population. The intention is to describe the variety of agricultural practices and the variation of production parameters such as fallow length, length of cropping period, number of plots in agricultural rotation and size of plots as to assess the state of agricultural intensification and to find what are the environmental constraints to production. Conducted interviews also focus on the state of knowledge and awareness of producers about the pressures on land of climate change and population rise; then on producers' knowledge of mulching and composting as innovations that can help mitigate the effects of these two pressures. Finally, producers' reasons of adoption or non-adoption of these innovations are explored. This is done by the means of soil analysis and the interviewing of 62 producers across 8 different localities of Sandfly Island.

What is found is that producers across the island share the same agricultural practices of no-external-input bush fallow, except for one producer who farms his land under the system of non-shifting multi-cropping with mulching as input. Some few other producers who have integrated mulching in their shifting agriculture. Nevertheless, producers from higher population density areas are shown to have shorter fallow lengths, to clear smaller gardens and to generally have less available land for production than producers from lower density population areas of the island. Producers who have less land available for agriculture also tend to have shorter fallow lengths; they occur in majority in high population density areas but not exclusively. Evidence was found of pressure on land both because of intensification and because of changing climatic conditions as producers complain of longer periods of drought broken by more violent episodes of rain and decreasing agricultural productivity. It was also found that roughly two thirds of producers know of composting and mulching though only 10% of them have adopted the innovations. Adoption rates vary from one source of knowledge to the other: school teaching and workshops led to adoption rates of 10 and 20 % respectively. Reasons of non-adoption vary significantly across groups of producers as big landowners and producers from the less populated areas state threefold more often that the adoption asks for too much work. Big landowners mention 97% and 25% more respectively a need for guidance and a need for further knowledge to adopt the innovations. The argument that adoption goes against the custom way is mentioned by 23% of the population and is not stated in significantly different proportions across clusters. The island's soil analysis showed that there is great variability in fertility amongst soils of the island that can be traced to either a difference in topsoil accumulation and thus soil organic carbon amongst soils of similar origins, or because of different parent materials.

These findings imply that, despite bush fallow being an appropriate and efficient method to restore soil fertility in the conditions of Sandfly Island, the heavy non-innovative intensification of agriculture in zones of high population density is no longer ensuring long-term sustainability of land use. Climate change aggravates this pressure. Such a situation offers great opportunity for appropriate agricultural innovations that can help mitigate the pressures; such as contouring to reduce soil erosion, mulching and composting as soil amendment. Some producers have made the decision to adopt such innovations, showing that the process of innovation diffusion is on the way on Sandfly Island, though at an early stage. Stated reasons of non-adoption show that small landowners and producers from higher populated areas perceive a higher relative advantage to adopt innovative agricultural practices as they are keener to accept the higher labour input it requires. In comparison, big landowners and producers from low population density areas still have the possibility of non-innovatively intensify their land use without increasing labour input. In consequence, there are reasons to believe that diffusion will happen more effectively amongst small landowners and producers of high population density areas. Further research could bring relevant insight on whether this proves to be true.

Keywords: subsistence agriculture, fallow, mulching, composting, innovative intensification, Melanesia, climate change

A Story - and Popular Scientific Summary

When Karine Favresse and Baudouin Michelet started traveling around Melanesia in 2016, they were struck by the deleterious impacts of traditional agriculture on islands' natural resources and the quasi non-existence of other agricultural practices than those traditionally used for generations. Shifting agriculture and the use of fire to clear agricultural plots was observed all along their journey despite an obvious change in the conditions of agricultural production: more people to feed, a changing climate and slowly eroding ecosystems as a result. This situation was often worsened by large-scale resource destruction such as logging or mining. When passing through Sandfly Passage, Baudouin could observe surprisingly large areas covered with grasslands, a rare sight in the Solomon Islands' landscape that he attributed to an excessive pressure of agriculture on land. Coincidently, it was when dropping anchor along Sandfly Island's eastern shores that they met Charles Lui, a local islander whose way of production starkly contrasts with what they had observed elsewhere, for he only uses one garden that he crops permanently rather than shifting from plot to plot. They were struck by the abundance of the area in the food it provides and this different way of approaching production that seems to tackle many of the problems identified in the spread-out traditional "slash and burn" agriculture.
Thus this story came to the ears of the author and the idea of this research project took shape. Maybe a little too innocently, the author could not understand why local producers would not simply change their practices to follow Charles Lui's example if both the problems generated by traditional agriculture and the solution to such problems could be identified. The following work is an attempt to explore the mechanisms of agricultural intensification and how sustainability could be integrated in such intensification as to both individually benefit producers and globally benefit island ecosystems and thus communities. After much research and discussions, some reasons could be identified: first of all, the traditional way of production is more efficient in terms of labour than Charles Lui's system. Producers therefore usually prefer a system requiring less work as it maximizes their leisure time. On the other hand, it offers better harvests and requires less land. It was shown that those producers who come from villages of high population density have, for most, already changed their way of producing since the available space they have per producer is limited. The rotation in their agriculture has intensified to produce more food from the same area thus shortening the span of time between the moments they crop an area and by creating smaller gardens. This has happened to such an extent that soil fertility is being depleted: it causes yields to decline, displaying an opposite trend to the growing population and demand in food. Year by year, the gap between production and demand grows. Producers in this situation

were observed to more keenly accept the possibility of adopting the same practices as Charles Lui while others can still intensify their agricultural production without having to adopt practices that require more work. More globally, producers do not feel confident to start a new way of farming. Some because traditional ways should be conserved, others because they feel they need more guidance and knowledge about such practices before starting to use them. Surprisingly, some producers were found to already make use of the same practices though in a different way: they carry on with shifting agriculture but implement the practices to help restore soil fertility and thus extend the period of time they can crop a garden before having to move to another area. Ultimately, it also offers the possibility of extending their fallow periods and reach sustainability. This shows that the spreading of Charles Lui's practices are already on the way and that it could promisingly diffuse amongst those producers who need it the most in such a way that severe ecosystem destruction could be avoided and food security achieved.

Picture 1. Sandfly Island, view on Hugu Organic Farm from closest summit. Picture by M. Michelet

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Abbreviations

BS	Base Saturation
Ca	Calcium
CEC	Cation Exchange Capactiy
DIT	Diffusion of Innovation Theory
EBC	Exchangeable Base Cations
FAO	Food & Agriculture Organization
FST	Farming Styles Theory
K	Potassium
KGA	Kastom Gaden Association
Mg	Magnesium
N	Nitrogen
P	Phosphorus
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TN	Total Nitrogen
WRB	World Reference Base

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1. Introduction

Small island communities of the South Pacific are most vulnerable to the on-going problematic arising from global population increase and climate change (Mimura *et al.*, 2007). Indeed, their geopolitical and economical context, remoteness, exposure to extreme events, insular characteristic and the more tangible finiteness of land and natural resources place these communities on the first line of those called to adapt to the global challenges of our times. (SPREP, 2012)

In the Solomon Islands, one of the five independent nations of Melanesia, a sub region of Oceania in the South-Western Pacific, 84% of the population lives in rural areas and most rural livelihoods are derived from smallholder agriculture both as a means of subsistence and as a means of income-generation through export cash cropping and fresh produce marketing (Bourke *et al.*, 2006a). In such island communities shifting agriculture, with forest or bush fallow, is the traditional, most widespread, system of land-use. It is a well-adapted system for small communities with much available land but due to the rapid population growth, estimated to be around 3.6% a year on a national scale, agriculture intensifies as fallow lengths are being shortened and marginal land is opened to agriculture to cope with a rising food demand and reduced land and resource availability (Tutua and Jansen, 1994; Grayson, 2002; Jansen and Maike, 2010). While this system of land use is still ecologically viable in many places of the Solomon Islands, places with higher pressures can observe a general trend of a down-spiralling agricultural productivity and accentuated land degradation (Grayson, 2002). Already in 1984, Nesbit described the outcome as

> A decline in food self-reliance, with many villagers now spending much of their cash income from plantations on food that was previously produced in their gardens (Grayson, 2002)

The increased consumption of imported rice and processed goods rather than subsistence products that provide the base of mixed and nutritious diets (AusAID, 2006), has led to a frightening increase in overweight population rates that reached 50% for males and 60% for females in 2016 (NCD-RisC, 2017). Jointly, the high dependency of rural communities on their land and their immediate environment as well as their close proximity to the coast creates a high vulnerability context towards the effects of climate change.

1.1 Climate change

Climate change is an on-going reality for South Pacific communities and its impacts are well documented. As anthropogenic greenhouse gas emissions continue to rise, the Solomon Islands will be confronted to more and more severe changes in its weather patterns, biophysical parameters, coastal territories, fish stocks and marine biodiversity (Mimura *et al.*, 2007).

While average temperatures have been recorded to increase by 0.12°C per decade in Honiara and minimum temperatures by 0.17°C per decade since 1953; they are projected to continue increasing accordingly, reaching a 1-2°C increase by 2050 in function of global emission scenarios (PACCSAP and Solomon Islands Meteorological Service, 2015). Though rainfall is expected to increase, rainfall distribution patterns are disturbed and the precipitation increase is projected to happen in the wet season while decreasing in the dry season (Barnett, 2007); resulting in more extreme drought and flood occurrence as extreme temperature and extreme rainfall events increase (Australian Bureau of Meteorology and CSIRO, 2011; Tutua, Jansen and Logan, 2011). Tropical cyclones are expected to decrease in frequency and increase in intensity (Leisz, Burnett and Allison, 2009).

Sea levels are recorded to have risen by 8mm per year since 1993 and continue to rise with another projected 14-35 cm by 2050 depending on global emission scenario, causing increasing storm surges, coastal flooding and erosion. (PACCSAP and Solomon Islands Meteorological Service, 2015) According to average temperature and carbon dioxide concentration rise, sea surface temperature is expected to increase by 2.1°C by 2100 and ocean pH to decrease by 0.3 to 0.7 units (Leisz, Burnett and Allison, 2009; Australian Bureau of Meteorology and CSIRO, 2011) .Together, these changes in marine ecosystems are causing marine habitat destruction, mainly because of coral bleaching, inducing a loss of biodiversity and a loss of reef productivity (Leisz, Burnett and Allison, 2009).

How these changes in conditions impact food production is multi-faceted. On the one hand, rising temperatures are expected to increase soil fertility through a higher input in SOC as photosynthetic processes are accelerated and boosted by a higher partial CO_2 pressure and temperature (Sombroek and Brinkman, 1996). On the other hand, while all crops have an optimal range of temperatures for favourable growth, the expected increase in temperatures in the tropics will reduce yields of tropical crop as most of these are already in the higher range of their favorable growth temperature (Masters, Baker and Flood, 2010). Soil water will also become less available to plants during the dry season as evapotranspiration increases; and water and wind topsoil erosion will have higher impacts during both seasons as drought and flood events become more extreme (Karmakar *et al.*, 2016). Furthermore, crops yields and harvest will become less reliable by the rising possibilities of root heat damage and general plant heat stress (Iese *et al.*, 2014). The high contrast and the repeated alternation between wet and dry season conditions as well as the rising strength of slaking will have a destructive impact on soil structure, increasing soil exposure to erosion and crusting (Karmakar *et al.*, 2016). Moreover, gardens are reported to be more susceptible to pest outbreaks in wetter conditions (Iese *et al.*, 2014) and rising temperatures can also lead to increasing pest reproductive rates and frequency of new diseases or invasive species (Padgham, 2009). Finally, with the rising of the sea level, flat coastal areas' soils are subject to salinization, causing stunted and uneven plant growth (Chen and Mueller, 2018).

One might speculate that ecosystem vulnerability to fire will increase during dry season thus the use of fire to brush fallows could come to pose a threat to the island's ecosystems as it may lead to destructive bush fires during more extreme periods of drought. All in all, for small island communities, this points out to a declining reliance on marine ecosystems to provide food thus transposing pressure on land ecosystems to fill the gap. Though at the same time, production conditions on land are deteriorating.

1.2 Demographic change and agricultural intensification

On a global scale, when population increases in social groups, there are more people to feed and agriculture has been observed to evolve accordingly by increasing cropping frequency of arable lands, thus producing greater outputs. Many theories have been established to try to understand which are the factors influencing agricultural growth; Ester Boserup in 1965, approached the question in a novel way by arguing that population growth is the cause of agricultural growth and not its result, contradicting long-accepted Malthusian theories.

Though Boserupian theories have been much criticized as they are shown to be limited to certain cases and cannot be generalized, they were developed by observing such communities as the one that is the subject of this research (Grigg, 1979) and therefore are much adapted to the pre-industrialized farming and limited land availability conditions of Sandfly Island.

In Boserup's book, "The conditions of Agricultural Growth", agricultural growth is broken down in 5 stages of systems of land use, distinguished by an increasing intensity and decreasing fallow periods, that occur in succession in areas of increasing demographic levels: Forest fallow, Bush fallow, Short fallow, Annual cropping and Multi-cropping.

Boserup explains this by showing that a higher frequency of cropping an area, thus a higher intensity of land use, provides higher total outputs but requires a higher input of labour (man-hours) to reach the same levels of food output as a less intensive system of land use. Thus, when agriculture intensifies, efficiency of labour drops characterized by a drop in output per man-hour. Accordingly, Boserup's conclusion is that a producer only has enough incentives to give up an extensive system, in which produced output is adequate and leisure is maximized, when population has risen high enough to provide the necessary additional labour force and to require a higher total output.

In the case of the Solomon Islands, population has been increasing quite steeply for several decades and agriculture has been observed to intensify though very few producers have undergone an abrupt change in land use system as the one described by Boserup (1965) (Grayson, 2002; Bourke *et al.*, 2006a). Subsistence producers keep on with the system of shifting agriculture and either forest of bush fallow. Agricultural intensification has mainly happened in a non-innovative way by shortening fallow lengths and prolonging cropping periods but very little innovative intensification has taken place (Laney, 2002). Though in such intensifying conditions, Boserup (1965) points out that other ways of preserving or regaining soil fertility must be introduced i.e. innovative intensifications. Indeed, Boserup (1965) describes that in pre-industrial communities under the system of bush fallow in need of agricultural intensification, producers will either start irrigating crops or introduce ploughing with draught animals providing nutrient-rich manure that contribute to restoring soil fertility. When agriculture reaches higher levels of intensity, chemical inputs take the place of manure. Very few innovative intensification practices have been adopted in the traditional land use system of Solomon Island producers: fire is still a central technology to clearing fallows, sticks are used to locally hoe ground and the introduction of the machete and of new short cropping-period staples like kumara and cassava by colonizing Great Britain during the 20th Century (Laracy and Foster, 2020) appear to be the only innovative intensifications that have made their way to a generalized adoption during the past several decades. Furthermore, many islands' rough terrain present conditions unsuitable for ploughing and though some grasslands may provide pasture areas, it is hard to conceive transport of draught animals overseas with the state of transport infrastructure. Additionally, the high price of cattle does not well fit the economical constraints of producers. Irrigation is hardly conceivable in many places as most streams from small islands are rain fed and run dry during the dry season when water is needed the most; rainwater harvesting, though not a focus of this study, is often spread out amongst households, though harvested volumes barely provide enough for human consumption in times of stress. The use of chemical fertilizers, pesticides and other industrial technologies is heavily constraint by the local economic context, access to market and transport infrastructure.

Nevertheless, one can find an abundance of studies and documentation about innovative intensification practices that could effectively contribute to help producers achieve a sustainable use of land and resources while at the same time helping to build up resilience in their production systems towards climate change. All in all, these adaptations extended by many NGO's and even by the national government commit to enhance a subsistence economy that ensures insulation or livelihood resilience in case of economic or agricultural stresses (AusAID, 2006). Simultaneously, they offer an appropriate response to the need of fertility restoration methods pointed at previously while being a convenient fit to the geopolitical and economic contexts of Solomon Island rural communities (Bourke *et al.*, 2006a; Jansen and Maike, 2010; Live&Learn Environmental Education, 2011; Tutua, Jansen and Logan, 2011). Such innovation is already being adopted in places of the Solomon Islands and while it represents an opportunity for many, it is becoming a necessity for others (Grayson, 2002; Tutua, Jansen and Logan, 2011). In Boserup's work, very little is said on how major changes in land use intensity happen, other than that the right demographic status should be reached and that some blockages such as knowledge of other practices can set back the adoption of a new system of land use. It almost feels as if, once the right conditions united, it just happens. To understand how innovation might come to spread out amongst communities and what are the factors influencing its diffusion, an economical and social psychology theory on the adoption of innovations has been adapted to innovations in agriculture and is, in this study, further applied to the specific case of innovative intensification in the case of communities with a rising demography and reaching the limits of non-innovative intensification possibilities. Furthermore, land use intensification seems to always be attributed to a producer's decision to increase output, either for coping with a higher food demand or to increase income. The threat of climate change on food production is a problem of our times and one must ask the question: can such a threat be taken into account in a producer's land use conception process?

1.3 Research objective

Thereupon, this study is conducted on Sandfly Island, an island of the Solomon Islands' Central Province as a practical case to assess the extent of demographic and climate change pressures on natural resources and the general environmental context from which subsistence producers derive their livelihoods; then to explore how smallholder agriculture is affected and currently developing to cope with the two pressures. To achieve this, a baseline description and analysis is made of the island's natural resources and how they are locally used as well as a description of livelihoods and agricultural practices. Building on this baseline, data is collected about local perception of demographic and climatic changes and their threats or impacts; about producers' knowledge and use of novel agricultural practices that could help mitigate pressures; about the source of such knowledge and the general arguments in the process of adoption or non-adoption of these practices. Data is analysed to observe trends of how practices and arguments might differ across the island in function of age, community population density and land ownership.

To sum it up, the objectives of this research are to answer the following series of questions:

- What are the different soils of Sandfly Island, how do locals identify and distinguish them and does such identification match results of laboratory soil analysis?
- What are the local agricultural practices, how are they embedded in local livelihoods, how do these differ from one producer to the next and what are local constraints?
- How do locals perceive climate and demographic changes, what are their symptoms on Sandfly Island, how do they affect production?
- Which innovative intensification practices would be suitable for the production context of Sandfly Island?
- What is the current state of diffusion on Sandfly Island of innovative intensification practices that help mitigate the problems raised by climate and demographic changes?
- How are the afore-defined innovative intensification practices generally perceived by Sandfly Islanders?
- How can these practices be expected to diffuse amongst producers of Sandfly Island?

The overall aim is to answer the ambitious question of why should- and how can agricultural innovative intensification benefit subsistence producers while integrating climatic and demographic changes in Melanesia.

2. Theoretical Background

2.1 Soil fertility and indicators

Assessing soil fertility is an arduous task as it asks for an oversimplification of the complex, living system that is the soil. Soil fertility is defined as the soil's capacity to provide a plant with the essential nutrients throughout its entire period of growth without exposing it to toxic levels of any element (Jensen and Husted, 2009). As can be seen, there is no mention in this definition of climate conditions, soil microbial population or presence of higher soil organisms nor of specific

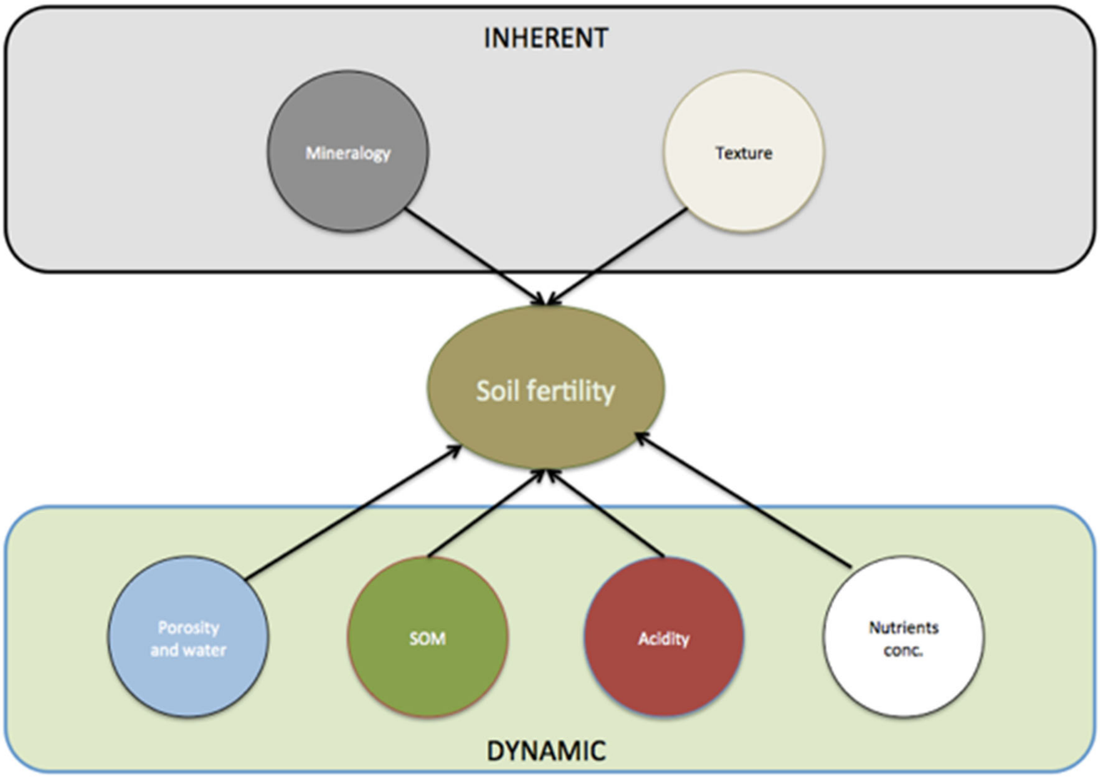

Figure 1. Inherent and dynamic fertility parameters. Made by M. Michelet based on Jensen & Husted (2009)

crop requirements: soil fertility designates a generic potential for plant growth and does not guarantee its release. Indeed, no matter how fertile a soil is, if no rain falls during the growing season or if high temperatures/fire destroys the soil's biological activity, considered plants might have a hard time to grow while some others might grow well, and the previously given definition of soil fertility would lose its meaning.

Soil fertility is traditionally broken down in two categories: dynamic and inherent parameters are shown in Figure 1.

2.2 Shifting cultivation

Agriculture in the Solomon Islands is based on the principle of fallow as soil fertility restoration method. Depending on a series of factors such as available space and ancestry, households make use of a various number of plots called "gardens" that they crop in a rotational succession. As fertility on one plot drops, it is left behind for natural vegetation to grow back and initiate a mining of the soil's nutrients by the growing vegetation. In the meantime, a plot that was left fallow for a period of time is cleared, traditionally by the method of "slash and burn" where vegetation is burnt down to restore those nutrients trapped in plant materials to the soil under the form of ash. In such a system of land use, it is imperative that fallow periods are adequately long to fill the fertility gap caused by the cropping period, as to maintain a sustainable cycle of successive fertility drop and build-up where no long-term depletion occurs. Figure 2 shows how production potential and soil fertility are highly influenced by the length of fallow in function of

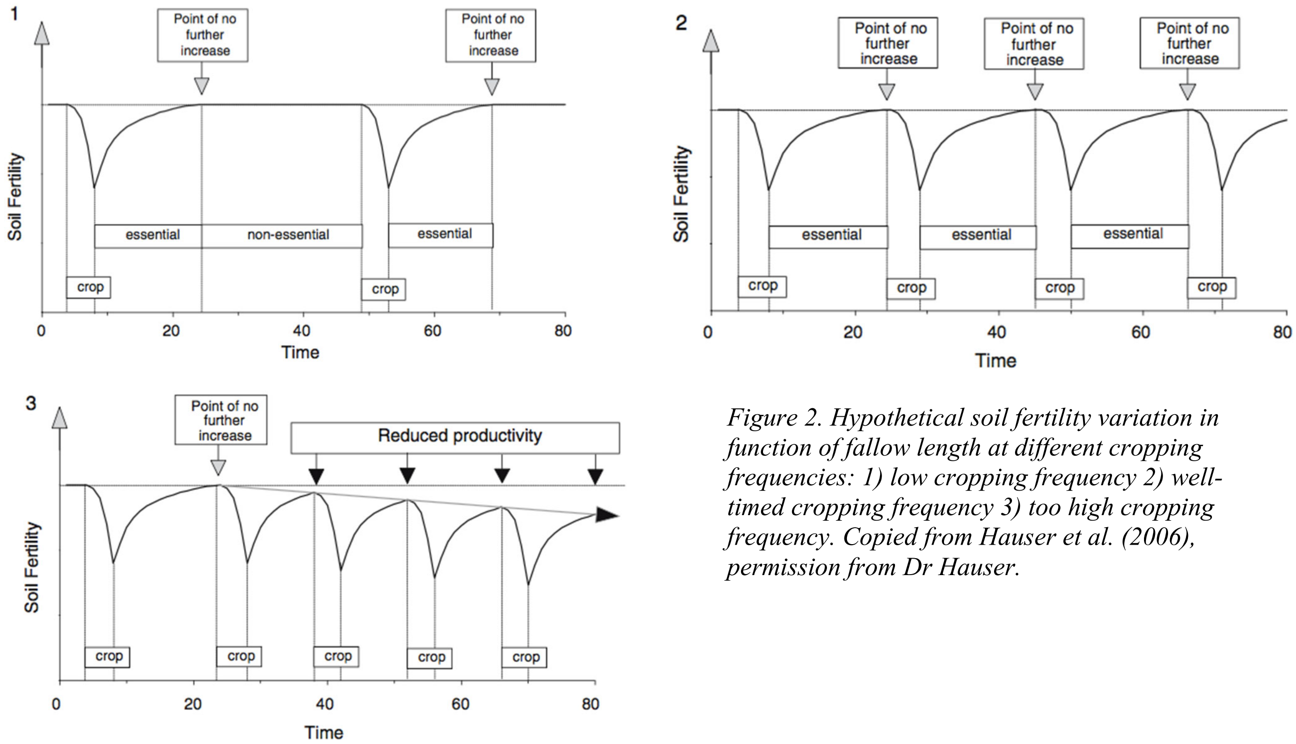

Figure 2. Hypothetical soil fertility variation in function of fallow length at different cropping frequencies: 1) low cropping frequency 2) well-timed cropping frequency 3) too high cropping frequency. Copied from Hauser et al. (2006), permission from Dr Hauser.

the frequency of cropping. Productivity is reduced if an essential fallow length is not respected (Hauser, Nolte and Carsky, 2006; Hauser and Norgrove, 2013)

2.3 Intensification of agricultural systems

Some traits are common to any shift between systems of land use and as a community moves up the gradient of intensification Boserup (1965b) describes the community will encounter:

- A higher total output of food produced.
- The need for more, and more intense, labour/man-hours per area as the efficiency of labour drops, especially when there is a lag in technology. This drop in efficiency of work translates into a drop in leisure and in short-term economical efficiency.
- A need for a sophistication of technology as some changes in technology will only materialize with an intensification of land use while at the same time some intensifications can only occur when new tools are introduced (Boserup, 1965a). Generically, the axe, fire and fallow are used to work the land and restore fertility when population is low enough. The hoe appears with bush fallow, plough and draught animals with short fallow, irrigation and/or fertilization by organic or chemical material with annual cropping.
- A general change of land tenure system drifting towards a privatization of the land and consequent shifts in social structures.
- A support of higher proportions of non-agricultural activities such as education, craft and administration as social structures change and output per area increases. This contributes

to the improvement of agricultural productivity by providing development in technique and technology.

- A higher capital investment required for a more intense land use.
- New knowledge about new techniques; though it is a frequent misconception that techniques need be discovered at each change of system. History shows that most practices were known or used partially by a population or its neighbours long before they are introduced to the generalized system of land use. Nevertheless, transfer of knowledge is rarely instantaneous and may cause a setback in change in land or tool use.

A measure of land use intensity is Ruthenberg's cropping index R-value, defined as the ratio between the number of years a plot is cropped and the number of years it is cropped and under fallow. An R-value of 33 or less indicates that land is under the system of shifting cultivation. An R-value above 66 indicates land is permanently cropped and values in between reflect semi-permanent fallow systems (Ruthenberg, 1980).

2.4 Innovation in agriculture: Diffusion of Innovation Theory (DIT) and Farming Styles Theory

The theory of Diffusion of Innovation developed by E. M. Rogers in 1962 describes how an innovation (a product, an idea, a behaviour) spreads out in a social group; it has been shown to successfully describe processes in the field of agricultural innovation (LaMorte, 2019). In the case of this study, DIT is used to look at the diffusion of agricultural practices that are not yet used by local producers and thus these new agricultural innovative intensification practices are at the core of the notion of innovation explored in the following texts.

The process of diffusion of such innovation is broken down in three major components. The first component describes that people go through 5 distinct stages in the process of reaching a decision about an innovation: awareness, persuasion, decision, implementation and confirmation.

Rogers (1983, 1995) explains that innovation is not adopted at the same speed for everyone and everywhere as information spreads heterogeneously and because people differ in characteristics; in fact empirical evidence shows that the rate of adoption of an innovation in a social group

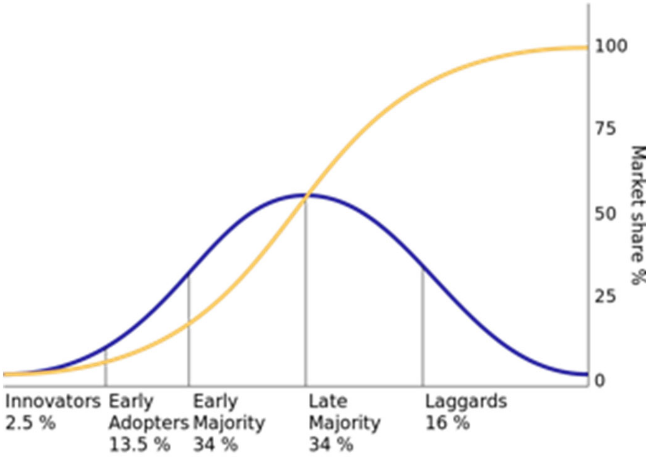

Figure 3. Diffusion of innovations according to Rogers. Successive groups of decision-makers adopting the innovation is shown in blue and follows a normal distribution while market share is shown in yellow and follows a sigmoid distribution. Retrieved from www.wikipedia.org

approximately follows a Normal distribution. The second component of DIT partitions the population of adopters in five groups in function of their standard deviation from the mean of distribution, and attribute common characteristics to the different groups (Figure 3). Thus, innovators are the first to adopt an innovation for they are alert to the appearance of new ideas; such individuals, while often described as venturesome and able to cope with high uncertainties, have little to no influence on the other groups. Early adopters follow innovators, they are often much respected and considered as role models by their peers and therefore are expected to have the strongest influence on the adoption by other groups. The early majority is constituted of deliberate individuals who interact a lot with others and, though they make an important link between those adopting early and those adopting later, they tend to not hold a position of influence amongst peers. The late majority is made of those cautious individuals who wait for evidence of success before adopting the innovation; it is argued they will only go through the process of adoption under pressure from peers. Finally, the laggards' group is made of individuals of a suspicious and traditional nature; they are the last ones to adopt the innovation.

Rogers (1983, 1995) and (Swanson *et al.*,1984) make use of such partitioning by advancing that the diffusion of an innovation can reach a level of self-sustained adoption, thanks to mouth-and-word communication, once awareness is raised amongst innovators and once promotion amongst early adopters is successfully done.

The third component identifies five characteristics of an innovation that determine its adoption rate:

- The relative advantage of an innovation is a measure of the perception of a decision-maker on how superior the innovation is compared to the practice or technology it supersedes. It is thus a subjective view of the benefits to adopt the innovation and may be given in many dimensions- be they economic, social or of any other type.
- Compatibility evaluates the consistency of an innovation with potential adopters' needs, traditions, values and past experiences. It is correlated to relative advantage as the more compatible an innovation, the higher relative advantage it offers and vice-versa (Rogers, 1995).
- Complexity gives an indication of the effort required to understand and apply an innovation; the more complex, the lower the adoption rate of an innovation.
- Observability describes the degree at which the results of the adoption of an innovation can be evaluated and seen.
- Trialability is the degree to which an innovation can be tested out or sampled before having to make an adoption decision.

All these characteristics have a positive correlation to the adoption rate with the exception of complexity.

It is important to note that DIT is based on the notion of a population of potential adopters and explores adoption rates within that population. In facts, such a population does not encompass the total population of producers of a social system. Farming styles theory (FST) describes that the interaction of social, cultural and structural factors in the environment of a producer are responsible for the emergence of finite and discrete sets of strategies and behaviours in agriculture that are called farming styles. Structural factors group economic, biophysical and technological constraints in a producer's environment that influence the strategies that are available to him (Howden and Vanclay, 2000; van der Ploeg, 2000; Mesiti and Vanclay, 2006). Producers that are affected by the same environmental constraints and contexts can be predicted to have similar farming styles and consequently a similar behaviour towards an innovation as an agricultural innovation is a means of changing or lifting limiting practical constraints. The population of potential adopters of an agricultural innovation therefore consists of those producers of the same cluster of farming styles for which the innovation offers a relative advantage. (Kaine, 2008)

Picture 2. Huts and gardens of Siro Community High School. picture by M. Michelet

3. Materials and Methods

3.1 Study site description

The study is conducted on Sandfly Island, the western most island of the Florida Islands group in the Central Province of the Solomon Islands, Melanesia.

Figure 4. Map of the Solomon Islands and provinces. By CartoGIS Services and ANU (2020). Sandfly Island is framed by the red box.

Sandfly Island has been given various names over time. Spanish navigators were marked by its abundance of flowers and named it Isla de Flores; elders know it by the name of Mbokonimbeti – "what lies at the end"; it figures as Olevuga on certain maps; Sandfly island is how everyone knows it nowadays even though its people seem divided on why it is named so: according to some it is because a British ship named "Sandfly" was anchored along its shores and its entire crew was slaughtered by the islanders, of proud warrior lineage, during the night. According to others, because, as the wind blows from a certain direction, it carries fine sand from a beach that then flies around the island.

The climate is wet equatorial, average temperatures stay almost constant around the year at 26°C, monthly precipitations vary seasonally in a wet and dry season pattern and add up to 3000mm per year (Allen *et al.*, 2006). The dry season, between May and November, can only be called so in contrast with the wet season, taking place from November to April under the influence of the northwesterlies, as there is at least 100 mm of rainfall during the driest months of the year.

The palm tree-shaped island spreads over 27 km^2 and displays a 100-meter high ridge of hills in its centre, rising to small peaks along its line: the tallest one rises 304 meters above sea level and is called Mount Panamanauvi on maps and Maxwell hill by locals. Flat land is scarce and can only be found along the coast where coral sandy beaches alternate with mangroves and where all villages stand and therefore all inhabitants live. The island is split in two districts: Ravu to the north is the less populated of the two (800 inhabitants), has a school and received partial funding to build a health centre; Leitongo to the south is by far the more populated (1400), has two primary schools, one high school and one medical centre. The dispersion of the population in various village zones is shown in Figure 11 (p.39).

Two network towers from OurTelekom and Bmobile are the only two modern infrastructures if rare concrete constructions are put aside i.e. churches, schools, medical centres and some rare houses. Sandfly Islanders live in wood and leaves huts made with material of the surrounding bush, go around either by foot along earth tracks, by wooden canoes along the coast or, for a small minority, by off-board motor boats and rely on rain water harvesting to drink and on small solar panels and batteries to power light bulbs, radios and cell phones. Some islanders organize a trade of basic goods from the capital city, lying 50 km away across Iron Bottom Sound, and sell rice, tea, sugar, salt, canned tuna, oil, noodles and sometimes fuel for a decent price in what is locally called a canteen. The Saturday market, organized in every major agglomeration, marks the only other place where money changes hands.

Every household with very little exception is responsible for the production of its own food consumption, doing subsistence farming. Gardens, the cropped plots of the local shifting agriculture system, are scattered around the island and produce the starchy tubers, vegetables and fruits that constitute the population’s daily diet (see results section); fish from the surrounding coral reefs as well as pigs raised on the island offer the only source of animal protein. Very little people therefore rely on incomes: selling the unnecessary excess of food harvested on the local market or selling fish both locally or at Honiara’s central market ensures enough income for households to provide for basic needs such as school fees, clothing and possible household expenditures. Some other livelihoods include carpentering, teaching and carving wood to sell to tourists in surrounding resorts.

Society is organized in a matriarchal, tribal structure.

3.2 Demographic change on Sandfly Island

Sandfly Island is described by Allen *et al.* (2006) as one of the most densely populated areas of the Central Province and as being amongst the places with the highest land use intensity of the country with a moderate to high pressure on land. These statements are, on the date of publication, 14 years old, and the state of pressure might have evolved. The island's total population at the last census of 2009 approximates 2200 people with a declining average annual population growth rate of 1.9% (measured) to 2.5% (with census undercount corrector) (Solomon Islands Ministry of Statistics, 2009); older annual population growth rates show 3.5% from 1979 to 1989 and 2% from 1990 to 1999 (Allen et al., 2006) for the Central Province. Despite a declining annual growth rate, annual population increase is still in the rising. (Solomon Islands Ministry of Statistics, 2009) Population density, as for 2009 is of 82 inhabitants km^{-2}, contrasting with the provincial and national averages of 35 and 15 respectively (Allen et al., 2006). The high land use intensity of Sandfly Island describes a shortening of fallow lengths and the extension of agriculture to marginal land.

3.3 Sandfly Island geology

As can be seen in the zoom on Sandfly Island and legend in Figure 5, Sandfly Island's geology is composed of two distinct layers of mafic pillow lavas partly metamorphosed from the Eocene to Oligocene called the Naghotano volcanics; topped by the Mboli Beds: a sequence of sediments (the Kombuana Sandstones) and andesitic lavas (the Soghonara Lavas) from the late Oligocene to Pleocene (Ministry of Land and Housing, n.d.). The transect in Figure 5 shows that the recent uplifting and tilting to the South play a major role in the moderately rugged landscape and the succession of peninsulas and small bays of the island. It also creates a gradient in the age of outcropping layers with the younger Kombuana Sandstones and its Soghonara Lavas rare

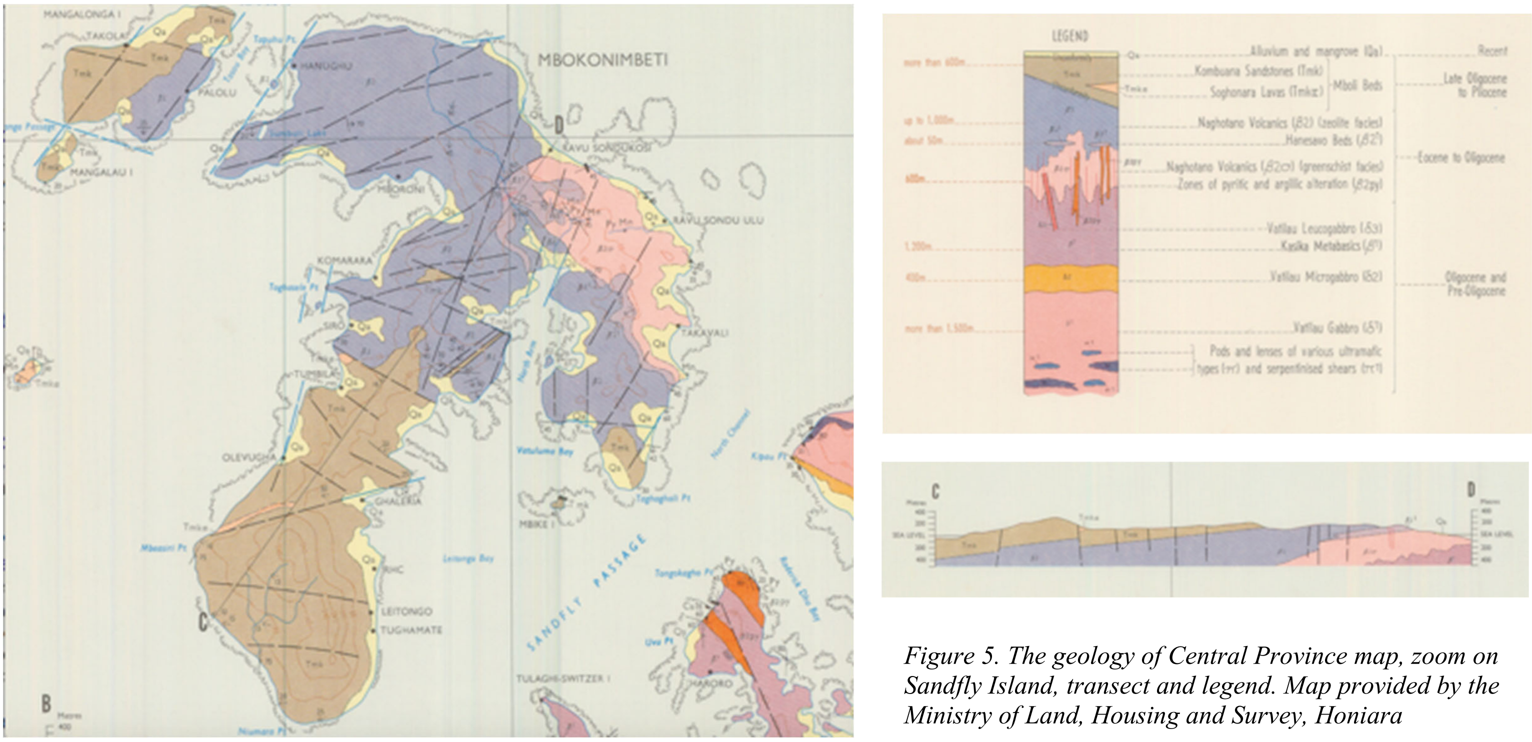

Figure 5. The geology of Central Province map, zoom on Sandfly Island, transect and legend. Map provided by the Ministry of Land, Housing and Survey, Honiara

inclusion to the South, the younger Naghotano volcanics with the zeolite facies outcropping from the central to the North-Western areas and finally, the older Naghotano volcanics with greenschist facies to the utmost North-Eastern areas, as can be observed on the zoom on Sandfly Island of Figure 5. In flat areas along the coast, coralline debris and mangrove and alluvium have contributed to creating a recent parent material depicted in yellow in Figure 5. Seismic evidence suggests that the region's coasts are defined by a fault in the continuity of the Kaipito-Korighole fracture of Santa Isabel, the bigger island to the North-West of Sandfly (Hackman, Taylor and Liha, 1977).

3.4 Innovative intensification practices on Sandfly Island

In the context of this study, innovative intensification practices designate agricultural practices that provide producers with means of fertilization adapted to the local context of an isolated community within a developing country. An analysis of such practices and the effects one can expect from them is more broadly done in the Discussion section. Some producers of Sandfly Island have already adopted mulching, as it is described in the section "The case of Charles Lui". Mulching, in this case, and how it is viewed throughout the study consists of the application of organic waste and litter directly upon the fields, chopped down into rough pieces then spread as homogeneously as possible all over the area, leaving the base of crop shoots bare. Mulching is done regularly and as often as possible as to permanently cover the soil with decaying material. The material used is collected from the surrounding bush and from kitchen waste, if it is not fed to pigs, and therefore is quite heterogeneous. Some material is observed to be more appropriate for such use, for instance banana tree trunks are shown to provide quickly decaying organic material in contrast with thick ligneous branches.

Kitchen fire ashes and pig manure are nor used for agriculture.

3.5 Soil sampling and analysis

The soils of Sandfly Island were sampled during an initial field trip in August 2019 in the attempt of mapping out soil resources diversity and to be further explored as an influence to the farming context.

The sampling was done in the following steps:

- Soil pit was dug down to 80-100 cm.
- GPS location was determined with a handheld device.
- Master horizons were identified.
- Written description of profile was done.
- Sampling of each master horizon: soil was collected along the horizon in a sealed plastic bag.
- Measuring of bulk density
- During the field trip, sample bags were kept open on dry days.

Samples were kept at 6°C in a fridge until they could be blown-dried on 19/11/2019 at 40°C in an oven in SLU, Uppsala. In the context of the course MV0208, Research Internship, a series of measurements were conducted of the sampled soils' properties to assess compared fertilities. This was done under supervision of Erik Karltun from the Department of Soil and Environment of SLU. Here below is a summary of the protocols of the different operations done.

The different parameters were chosen to match those studied in the Climate, Livelihood and Production in the Southwest Pacific (CLIP) project carried out under the Galathea3 Expedition (Mertz *et al.*, 2012), inter alia in some islands of the Solomons so that comparisons between locations can be done for potential further studies.

Sample preparation

After drying the samples in an oven for 12 hours at 40°C, the 28 samples are individually sieved through a 2mm grid then ground with mortar and pestle then sieved again. The weight of the sample before and after the sieving is measured in order to assess the weight of the >2 mm fraction.

Moisture correction factor

Following instructions of the ISRIC manual of Procedures for soil analysis (2002), soil samples are weighed fresh with a 0.001g accuracy then dried in an oven at 105°C overnight. Dried samples are then weighed again with same accuracy and the following calculus determines moisture content of the sample:

$$soil\ moisture\ \% = \frac{A-B}{B-C} \times 100$$

$$mcf = \frac{soil\ moisture\ \% + 100}{100}$$

where:

- A= fresh soil sample weight
- B= dried soil sample weight
- C= weight of bare tin

The moisture correction factor is then applied to all following analysis to accurately describe soil parameters per dry weight rather than wet weight.

pH

The method described by ISCRIC (Reeuwijk, 2002) is used. 3 mL of each sample is added to a sealed test tube with 7.5 mL of deionized water. The samples are shaken for 18 hours then, after calibrating the Fisher Scientific accumet AE150 pH-meter, pH is measured.

Plant-available P

The Olsen extraction method is employed: the phosphorus of 3g of soil is extracted by a solution of sodium bicarbonate 0.5M at pH 8.5. Absorption of the samples is then determined colorimetrically at 882 and 720 nm by the blue ammonium molybdate method with ascorbic acid as reducing agent (Reeuwijk, 2002). Available P concentration is then determined with the Lambert-Beer law by building a regression absorption-P concentration curve with standards at both 882 and 720 nm. The final concentration is the average of measures at both wavelengths and is given by the equation:

$$P\left(\frac{mg}{kg_{soil}}\right) = \frac{(a-b) \times 100 \times mcf}{m}$$

where:

- a= mg(P).L^{-1} in sample extract
- b= mg(P).L^{-1} in blank
- mcf= Moisture correction factor
- m= mass of sample

Exchangeable base cations (EBC)

The ammonium acetate extraction method is used as described by Page, *et al.*(1982). The base cations are extracted from 5g of soil by a 1M-ammonium acetate solution then their concentrations in the extract is determined individually by atomic absorption spectroscopy (AAS).

A standard solution of 6 ppm Ca and 3 ppm K, Na and Mg is diluted to create a standards series. A regression curve is established by running the standards through the AAS and concentration in each base cation of each sample in ppm is determined by referring measured sample absorption to the base cation's standards regression curve.

To present concentrations of each base cation in cmol.kg^{-1}, the following equation is used.

$$CBC(\frac{cmol}{kg\ soil}) = \frac{C(ppm)}{M_{mol}BC} \times \frac{V_{extract}}{m_{soil}} \times \frac{1\ cmol}{10\ mmol} \times c \times mcf \times dilution\ factor$$

Where:

- CBC (cmolkg soil)= Concentration in cmol.kg^{-1} soil of a base cation
- $M_{mol}BC$= Molar mass of base cation in mol.g^{-1}
- $V_{extract}$= Volume of extracting solution, in this case = 0.05 ml
- m_{soil}= mass of analysed soil sample= 0.005 kg
- c= Base cation charge
- dilution factor= 100 in this case

Exchangeable acidic cations (EAC)

The KCl extraction method described by Buurman, Val Lagen, & Velthorst (1996) is used. 30 ml of 1 M KCl is added to 5 g of soil sample then the solution is shaken for 30 minutes then centrifuged for 15 minutes at 3000 rpm, the supernatant is then decanted and filtered to a volumetric flask. This operation is repeated four times. When the volume is homogenized for each sample, 25 ml is extracted then titrated by 0.01 M NaOH to endpoint pH 7.8. Exchangeable acidity is determined with the following equation:

$$Tot\ exch.ac. = \frac{(V-B) \times 8 \times mcf}{W}$$

Where:

- V= Volume of added NaOH to sample in ml
- B= Volume of added NaOH added to blank in ml
- 8= Conversion and dilution factor

- mcf= Moisture correction factor
- W= Weight of sample in g

Cation Exchange Capacity (CEC)

CEC is here operationally defined as the sum of EAC and EBC (Mertz et al. 2010).

Soil Organic Carbon (SOC)

Total carbon is analysed by dry combustion. Since some soil samples contained carbonates, another sample, pre-treated by heating to 600°C in furnace to oxidize organic carbon, is analysed by the same method to get inorganic carbon concentration. Soil organic carbon is then calculated as total carbon minus inorganic carbon.

Total nitrogen

Total nitrogen is determined by dry combustion, the protocol is the one followed by the plant analysis lab from the Department of Soil and Environment of SLU.

Bulk density

Bulk density is measured on sampling site by extracting a volumetric sample of 100cm^3 and by weighing it on an electronic scale. Bulk density is established as the ratio of weight by volume.

One can observe that no indicators for soil water and porosity are measured. This comes from the fact that these measures ask for a consequent undisturbed quantity of soil, more than could be brought back from fieldwork. This reason equally explains the absence of precise texture measurements. More information on how the analysed soil parameters relate to the parameters of soil fertility is explained in Appendix I.

3.1 Interviews

During a second field trip in January to February 2020, a series of interviews were conducted on Sandfly Island. A total of 62 people from 8 different localities were selected randomly and asked to answer a questionnaire followed by a recorded discussion under the form of an interview.

Table 1. Locations description and respective number of interviews

Locality	Interviews (n)	Approximate Population	District	District population density (inh./km^2)
Leitongo 1	9	400	Leitongo	100
Leitongo 2	10	400	Leitongo	100
Olevuga	6	400	Leitongo	100
Tubila	6	100	Leitongo	100
Siro	4	100	Leitongo	100
Ravu Sodulu	12	250	Ravu	60
Ravu Sodukosi	10	250	Ravu	60
Boroni	5	100	Ravu	60

Both the questionnaire and interview questions can be found in Appendix 4
Interview questions were orally asked in English and directly transcribed on paper by the author. The goal of such interviewing was to collect knowledge and data from around the island on the variety of farming practices, livelihood strategies, indicators of level of intensity of agriculture such as fallow and cropping period lengths, number of plots used in plot rotation, size of plots, type of soil used and degree of inclination of land used. Some questions aimed to gather data on producers' knowledge of agricultural intensification innovations (AII) and reasons of (non-) adoption as well as on producers' awareness and perception of climate change and local demographic changes. Interviews were conducted in eight localities with a variety in population size and district density context. See Table 1 and Figure 11 (p.41).

Three additional interviews with more specific questions were conducted during fieldwork. Firstly, Charles Lui (see the case of Charles Lui) was interviewed about customary land tenure, tribal land distribution, and customary law in a first interview on 07/02/2020; and about his personal adoption process of non-shifting agriculture, the reasons of adoption and recommendations to other producers in a second interview on 10/02/2020. Both interviews were summarily transcribed on the spot by the author. Many more conversations with Charles helped the author build an understanding of the human and agricultural dynamics of Sandfly Island, though left off the charts. Such discussions for instance, helped build an ethnopedological approach to local soils fertilities.
Secondly, an interview of Peter Mike, occupying the position of paramount chief of Gela, was conducted on 08/02/2020 in Boroni village. He was interviewed about his perceived changes in agricultural practices, productivity, population and custom over his lifetime. The interview was summarily transcribed on the spot by the author
Thirdly, Pita Tikai, leading member of Kastom Gaden Association (KGA), was interviewed about the story of KGA, the problems encountered in the extension of agricultural innovative intensification by KGA on 24/01/2020. The conclusions of the discussion were transcribed after the interview. All specific interview questions are listed in Appendix 3.

3.2 Conducting a workshop

The author organized a workshop entitled "Appropriate land use for a sustainable and resilient living" at the end of his second stay on Sandfly Island. It helped to experience first-hand the challenges that the extension of agricultural innovative intensification might entail, and evaluate local producers' perception of different innovations' complexity and compatibility as well as serving as a means, through group discussions, to assess local awareness and knowledge about demographic and climatic pressures on Sandfly. Ultimately, it also served as an obvious way of handing back to the local population the primary conclusions of the study they were part of.
During breaks and moments of group work, a survey was conducted amongst participants to collect data on types of crops farmed and use of private or tribal land in agriculture. A list of

crops was established and each interviewee was first asked to specify which of the crops he used in his gardens then how many plots of tribal and private land he used.

3.3 Statistical analysis

Fallow lengths, cropping periods, and number of plots and plot sizes were collected as quantitative data through the questionnaires and was processed for statistical analysis with Excel to find correlations between indicators of level of agricultural intensity and producers' age, district population density and size of farmed area. A series of Student and Chi-square tests were conducted to test hypotheses of correlation between data sets with a significance level of 0.05.

Qualitative data was collected on anecdotal evidence of climate change and population increase, producer's knowledge on composting and mulching as well as information on personal decisions of adoption or reasons of non-adoption. Reasons of non-adoption were summarized to 6 categories and thus could be processed as quantitative data and analysed with the same tests and levels of significance as the other quantitative data.

The quantitative data of the soil analysis was typed in an Excel sheet. The same methodology, appropriate for soil fertility analysis, was applied for every sampling and analysis and thus limits the significance of the part of the study aiming to compare soil fertilities in function of land use. Indeed, no replicates were collected for this purpose; no statistical analysis could thus be conducted. The lack of statistical indications such as standard deviations makes the comparison more informative than accurate.

3.4 Maps

Soil maps were built by the author using the free QGIS software. Figure 7 was built by observing on site the general trends of soil topographic distribution and concomitant vegetation then by manually demarcating satellite imagery in different soil zones. Figure 13 was built by observing on site the structure and distribution of Charles' garden. An initial sketch was made on paper then retrieved satellite data was demarcated in pre-observed zones as to, as accurately as possible, match reality. Coordinates are given in the CRS:WGS 84. Built maps also use EPSG :4326.

4. Results

4.1 System description

Soils

Inhabitants of Sandfly distinguish 5 different types of soil on the island by their colour or texture. This is often the case in indigenous soil classifications as Ettema (1994) tells us.

- *Pari Bili* means black soil. It can either be found in sloping areas where forest has developed over many years and organic matter has accumulated in the top layers or in fluvial plains and flat coastal areas. It is considered as the most fertile soil type of the island. In this study, the first type from slope areas will be referred to as brown soil while the second from the coastal plains as black soil.
- *Pari Sisi* means red soil. It is found in some rare sites on the top of the island's ridges, very scarce vegetation cover and it is known to be the poorest soil of the island.
- *Pari Saga* means yellow soil. It is found abundantly in the high grounds of the island, the great majority of the grasslands cover yellow soils. Islanders consider it as an intermediate fertility soil and occasionally farm it for some crops when no other land is available.
- *Pari Ubu* means sandy soil. It is found in flat areas around the coastline bordering coral reefs and consists of accumulated crushed coral debris. It is considered as a fertile soil type, if well managed.
- In addition, a swampy soil was mentioned.

Table 2 summarizes how locals perceive the different soils fertilities, describing what crop types can grown on what type of soil (more on crop types in section 4.1.3) where values attributed to each cell give an indication of how each crop grows on each soil type: the crop does not grow if value is zero; the crop grows but the yields are unsatisfactory if value is 0/1; the crop grows and yields are good if value is 1. This approach gives two sets of information: first of all perceived fertility of the different soils and second, knowledge on the different local crops' nutrient demand under local conditions. Such knowledge is precious as it gives better understanding of local

Table 2. Ethnopedologic approach to soil fertility; a producer's perception of how crops grow on different soils of Sandfly Island. 0= does not grow; 0/1= grows but poor yields; 1= grows and good yields.

Crop type:	Red soil	Yellow soil	Sandy soil	Black and brown soils
Banana	0	0/1	0/1	1
Pineapple	0	1	1	1
Pana & Yam	0	0/1	0/1	1
Cassava	0	1	1	1
Kumara	0	1	1	1
Taro	0	0	1	1
Sago palm	0	0	1	1
Coco palm	0	0	1	1
Mango tree	0	1	1	1
Betel palm	0	0/1	1	1

community practices (Breuning-Madsen et al. 2010).

In contrast with the local knowledge afore presented, soils of Sandfly Island were analysed by a team of scientists for the British Ministry of Overseas Development. A total of 8 soils were identified on Sandfly Island following the US Soil Taxonomy. These nuances are hard to precisely convert to the FAO World Reference Base (WRB) for soil resources. For the purpose of getting a more precise idea of the soils' fertilities, their description is given hereunder, as it can be found in the Land Resource Study 18 by Wall and Hansell (1976) of Choiseul, another island of the Solomon Islands. The soil map resulting from such studies could be purchased at the Ministry of Lands, Housing and Survey: it is represented in Figure 6.

1. The sandy soil is a lithic Troporthent (of the Entisol order), it shows little pedogenic horizon development other than a thick organic matter-enriched A horizon on top of a loose structureless coral sand with large coral fragments. Its fertility depends entirely on the extent of SOM accumulation as it is expected to have a very low CEC saturated with calcium and a strong alkaline pH due to a high level of carbonates; OM provides the only opportunity for a proper nutrient balance and the providing of otherwise deficient nutrients such as potassium. In the WRB it is classified as a sandy coral Arenosol.
2. The yellow soil is a Dystropept (of the Inceptisol order), showing characteristic low concentration of bases and low exchangeable acidity including iron and aluminium because of high drainage, little subsoil horizon development, a weak structure and fine to medium texture. It is found on Sandfly's volcanic ridges, its clay fraction is strongly weathered resulting in a low nutrient availability in the subsoil and the much-eroded topsoil barely compensates as Dystropepts show an absence of surface humus accumulation, K status is especially poor. In the WRB it is classified as a Dystric Cambisol.
3. The brown soil is a Eutropept (of the Inceptisol order) with quite similar characteristic as the Dystropept except for a higher surface accumulation of OM and a higher BS, they are positioned on the slopes of volcanic hills, are well drained and tend to be dark in color, base rich and stony. They consist of dark loamy topsoil on top of a yellowish brown lower B-horizon and present high levels of Mg and Ca and deficiencies in K throughout the profile. In the WRB it is classified as a Eutric Cambisol.
4. The first type of black soil is a Tropaquent (of the Entisol order), distinguished from the other black soil by its situation in locations where the watertable is permanently high: on the margin of freshwater swamps of lower water streams. It is characterized by a deep soil profile, poor drainage, high clay content, thin peat surface accumulation and thus are expected to have high nutrient contents though K might be limited. It is referenced as a Gleysol in the WRB.
5. The second type of black soil is a Tropofluvent (of the Entisol order), a loamy soil characterized by its position in the floodplains of the streams of Sandfly; it is formed in recent water-deposited sediments. Its fertility highly depends on the type of source rocks and soils that can be found upstream; in the case of Tropofluvents on Sandfly, they occur

below weathered soils and, though OM is high at the surface and through the profile, CEC is low, and base cation contents can vary greatly. It is equally referenced as a Fluvisol in the WRB.

6. The first type of red soil is an Acrorthox (of the Oxisol order), a deep profiled, very strongly weathered, deeply drained clay red soil with an angular blocky substructure, a strong acidity, a severe depletion of all bases, low nutrient levels, CEC and microbiological activity. It is said to occur only over ultramafic rocks. The WRB classifies it as a Ferralsol.
7. The other type of red soil is a Haplorthox (of the Oxisol order), a deep profiled, freely drained, reddish brown clay soil with a weak structure found in stable areas of slopes mostly less than 10°. Haplorthox resemble Acrorthox chemically though tend to have a somewhat higher CEC, BS, and higher levels of P. In the WRB, it is also classified as a Ferralsol.
8. Mangrove soils, close to the shore and within the influence zone of saltwater are Sulfihemists (of the Histosol order) and they consist mainly of mangrove debris accumulating and forming peat. High salinity and the presence of iron sulphides that are reacting to form sulphuric acid when drained and aerated, make them unsuitable for agriculture. In the WRB they are classified as thionic Histosols.

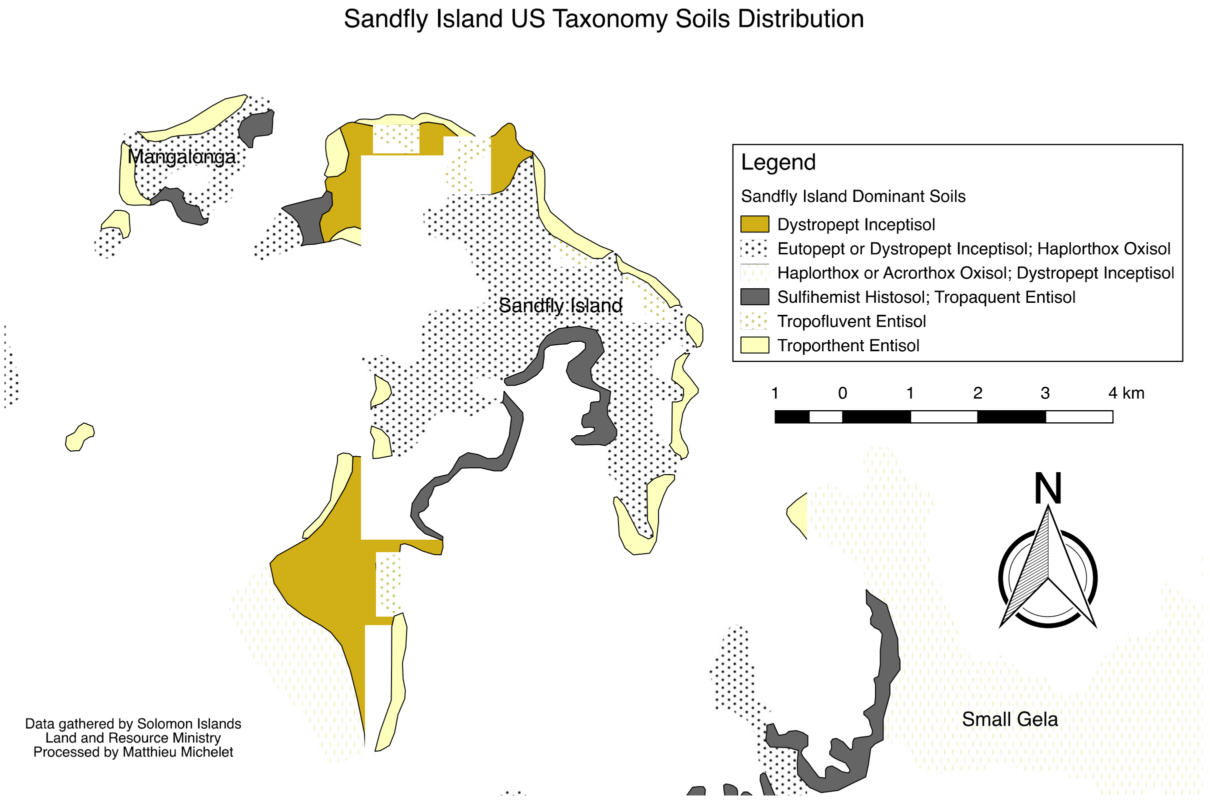

Figure 6. Sandfly Island US taxonomy soil map. Made by M. Michelet on QGIS with data from the Ministry of Lands, Housing and Survey of the SI

The spatial distribution of the soils is given in Figure 6. Many of these soils occur together in given zones, though belonging to the same taxonomic group, soils are bound to differ spatially in function of relief, vegetation cover and other local conditions and evolve from one group to another in gradients of variation: the analysed soil samples are just a measure of a single point in space and results should not too much be looked at in a quantitative way but rather as a subject to interpretation and as orders of magnitude (Landon, 1991)

Soil sampling was done following the indigenous soil classification and this study focuses on the 5 soil types locally recognized as they are the ones on which the most information is collected; the soil description sheet of the analysed profiles are in Appendix 4, results are given in Table 3.

Table3. Soil analysis results and parameters comparison of surface and 30-50 cm depth levels

Soil layers	pH	K^+ (cmol/kg)	Ca^{2+} (cmol/kg)	Na^+ (cmol/kg)	Mg^{2+} (cmol/kg)	Exch. Ac. (cmol/kg)	Total BC (cmol/kg)	CEC (cmol/kg)	BS (%)
Yellow soil									
0-30cm	6.1	0.05	0.1	0.1	0.28	1.0	0.54	1.54	34
30-50cm	6.9	0.03	0.1	0.11	0.29	0.8	0.54	1.34	39
Brown soil									
0-25cm	7.0	0.06	0.13	0.12	0.25	0.75	0.56	1.31	43
25-50cm	6.9	0.03	0.11	0.11	0.26	0.79	0.52	1.31	40
Black soil									
0-37cm	6.5	0.11	0.08	0.12	0.28	0.62	0.59	1.21	49
37-50cm	6.6	0.04	0.11	0.11	0.32	0.86	0.58	1.44	40
Red soil									
0-30cm	5.5	0.03	0.01	0.1	0.24	3.5	0.40	3.9	10
30-50cm	5.5	0.03	0.01	0.1	0.23	3.6	0.38	3.98	9
Sandy soil									
0-50cm	7.9	0.1	0.13	0.11	0.13	0.57	0.48	1.05	45
50-80 cm	8.5	0.04	0.13	0.14	0.11	0.46	0.42	0.88	48

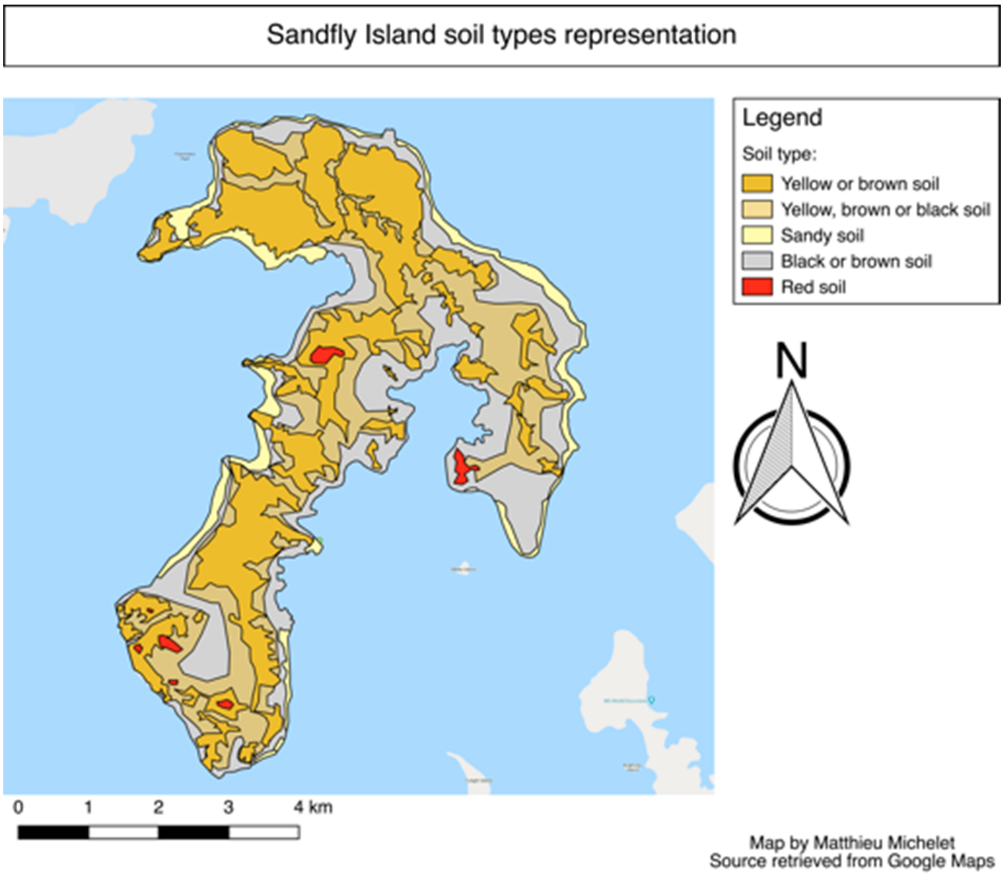

Figure 7. Sandfly Island soil map representation. Made by Matthieu Michelet based on Google maps satellite imaging data. Soil zones are attributed from on-site observations and based on vegetation cover observed from satellite imagery.

All soils display low levels of base cations. K^+ especially can be expected to be a limiting factor to plant growth; CEC is generally low, the sandy soil has the lowest one, showing that the clays of those soils that have some are heavily weathered. The pH of the red soil is critically low, due to severe weathering, and the sandy soil pH is quite alkaline, because of the high content of carbonates, and might impede plant growth; pH of all three remaining soils is appropriate though.

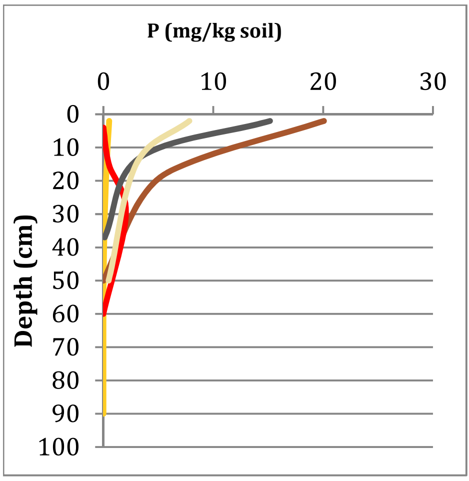

Figure 8. Comparison of plant available P amongst sampled soils of Sandfly Island.

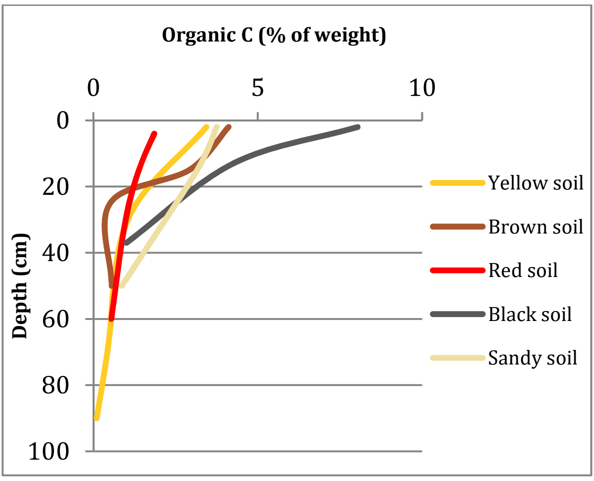

Figure 9. Comparison of soil organic carbon amongst sampled soils of Sandfly Island.

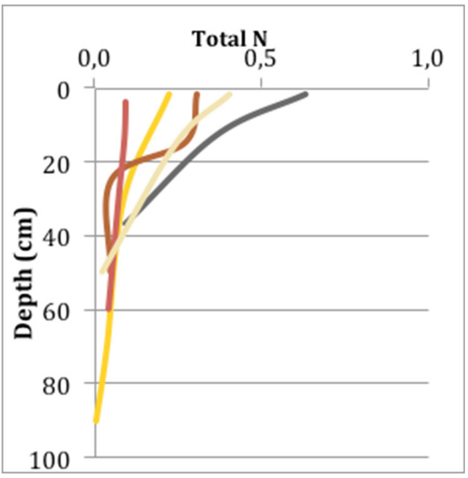

Figure 10. Comparison of total nitrogen amongst sampled soils of Sandfly Island.

Figure 8, 9 and 10 show that both yellow and red soils have very low levels of plant-available P and TN and low or intermediate levels of SOC respectively, especially compared to the brown and black soils that have high levels of the three parameters while the sandy soil has intermediate levels of P and high levels of both TN and SOC. The BS of all soils is intermediate though levels for the red soil are critically low. The yellow, brown and black soils have similar levels of base cations, CEC and BS but differ mostly because of a difference in SOC and the concomitant nitrogen it provides. The sandy soil and red soils differ significantly from the rest because of contrasting parent material. Figure 7 shows a modelling of the spatial distribution of soils based on local observations and satellite imagery.

Demography

Both literature (Bourke *et al.*, 2006b; Solomon Islands Ministry of Statistics, 2009) and on-site collected data agree to say that Sandfly population has been increasing over the last century; current count is around 2200 inhabitants of voting age (over 18) (Solomon Islands National Statistics Office, 2019). Data from the interviews shows that the average household counts four members, but depending on the age of the interviewed parent, household composition changes: the older generation (60-80) has in average 5.5 children whereas the younger generation (20-40) has 3 children in average and the middle generation (from 40 to 60) has an average of 4 children.

Population is spread out in larger, denser villages from the Leitongo district to the South and

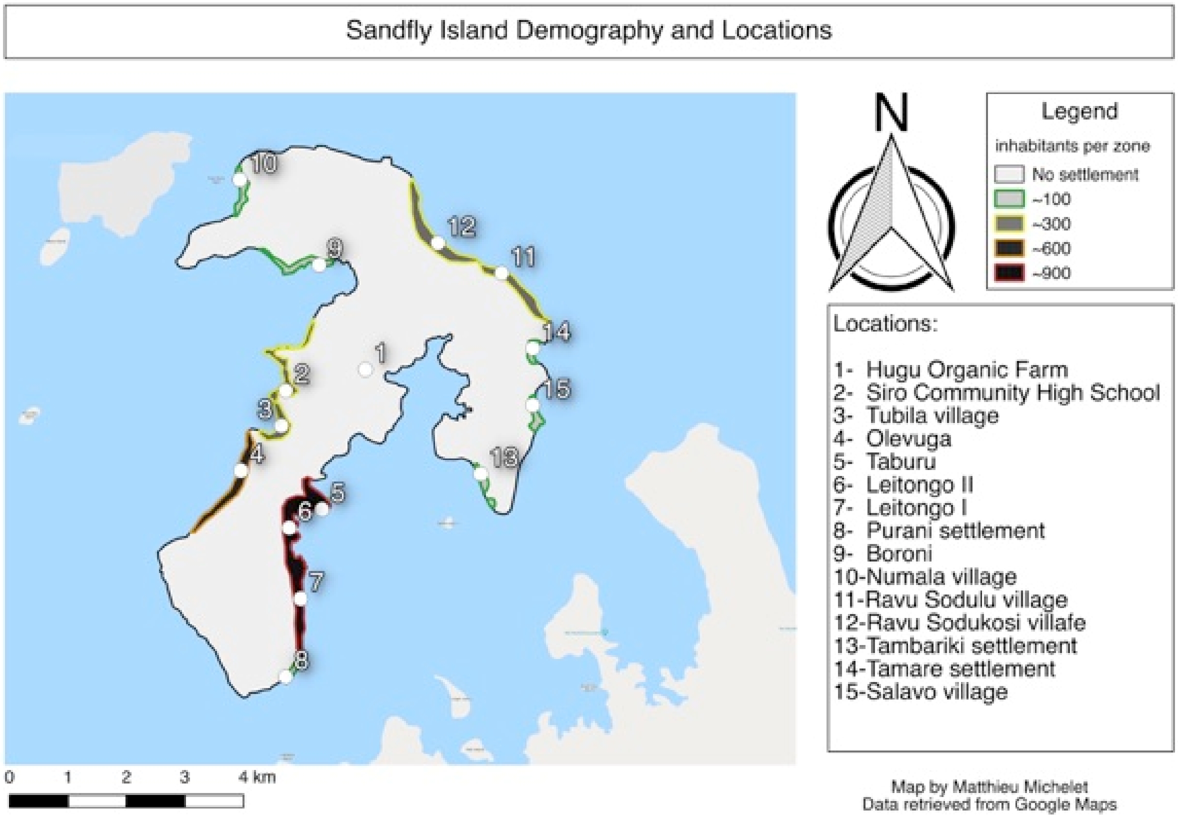

Figure 11. Sandfly Island demography and locations map. Made by Matthieu Michelet from on-site collected data.

smaller, less densely populated villages or settlements from the Ravu district to the North (Figure 11). Smaller settlements of a few families, often from a similar lineage, can be found all along the coast. All population belongs to the same ethnic group of Melanesians with a few exceptions coming from intermarriage with people from Malaita who are Polynesians. To the Northwest, the village of Numala (New-Mala) is historically a settlement of Malaitans.

The interview with Charles Lui revealed that there are three main tribes each split up in between 6 to 9 clans: the Kakau tribe of warrior lineage, the Gaubata tribe of chiefly lineage and the Hogokama. The entire population is Protestant, mostly Anglican with some representatives of the Seventh Day Adventist and United Church.

Livelihood strategies are most often based on subsistence agriculture and a low income through cash-earning activities in the informal sector. Data from the interview show that employment rate is 42%, though 28% if only considering employments of the formal sector, putting aside community services such as chief, chairman or church volunteer (Figure 12).

Of the population, 98% owns a garden and crops it for subsistence though only part of the population identify themselves as farmers; only one interviewee out of 62 did not own a garden, he is a teacher in Honiara and only spends his holiday time on Sandfly where he can rely on friends and family to feed him. The most usual cash-earning activity of the informal sector is fresh produce marketing, should it be crops or fish. Indeed, when interviewed about incomes, 76% of households stated to rely on crop marketing, 68% to rely on sales of fish either on local markets or the bigger central market of Honiara. The 22% employed in the formal sector rely on their salaries while 5% of households proclaim to live without income. A total of 53% of interviewed households rely on fresh produce marketing of both fish and crops.

Even though all producers stated that the food produced in gardens is enough to feed their household, 78% of families take part in local economy and buy food on the local market and canteens; either to buy staples or other crops during inter-harvest periods and to get some food diversity (49% of interviewed), or to buy rice or processed food (51%) like sugar, tea and biscuits coming from export or local production through Honiara.

Given numbers are homogeneous over the island and do not vary significantly amongst locations.

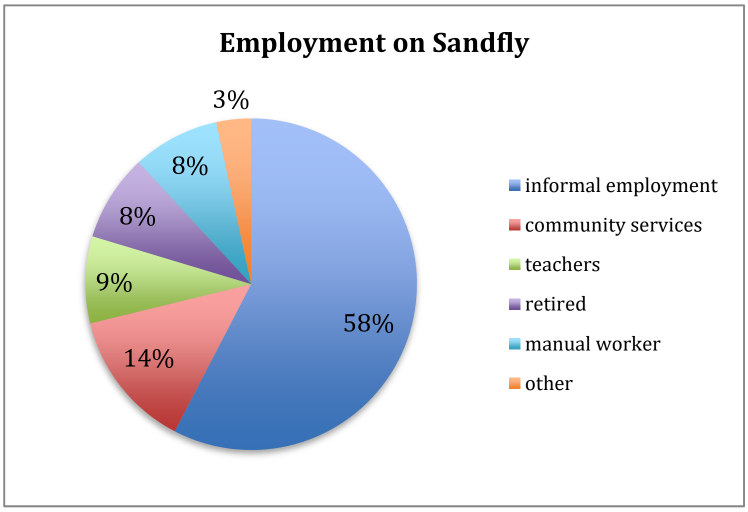

Figure 12. Results from interviews, employment on Sandfly Island.

Table 4. Comparison of fallow and cropping lengths, number of plots and average plot size across districts and age classes.

	Fallow length (years)		Cropping period (years)		Number of plots (n)		Average plot size (m^2)	
	$\bar{X}$	sd	$\bar{X}$	sd	$\bar{X}$	sd	$\bar{X}$	sd
Leitongo distr.	3.79	2.81	2.44	0.84	3.88	2.07	628	236
Ravu distr.	5.26	1.70	2.57	0.75	4.04	1.71	2013	2400
Young (<45)	4.33	2.11	2.38	0.66	3.62	1.58	1766	2663
Old (>=45)	4.80	3.16	2.60	0.89	4.21	2.11	3430	7520

Land use

Land on Sandfly is used under the system of bush fallow to produce starchy staples and vegetables in gardens and fruits and nuts in fallow and bush areas. Agriculture exclusively relies on brown or black soils though some farmers make use of sandy or yellow soils to supplement production: only one interviewed producer stated he uses yellow soil areas to crop cassava; two gardens on sandy soil were observed but no interviewee stated such use. The global average cropping period lasts 2.5 years (sd=0.68 years) and fallow periods average 4.7 years (sd=3.0 years).

Fallow lengths vary greatly from one farmer to the next. Data analysis shows that a producer's average fallow length differs significantly in function of the population density of the area he lives in and the size of the area he can use for agriculture. Indeed, average fallow period is significantly different, by two years in average, between those islanders who farm greater land area (>0.3 ha) than those with less land; and those farmers coming from the Leitongo district have in average a fallow period 1.5 years shorter than those farmers who come from the Ravu district. (Table 4)

No correlations were found between age of interviewee and analysed parameters of land use. Though there are no significant differences in the number of plots in producers' rotation across districts, the attributed size of plot is shown to be significantly larger for producers of the low population district of Ravu. Thus, producers from Ravu have significantly bigger average farmed areas (number of plots * average size of plots) than producers from Leitongo (Table 4). Length of cropping period is shown to positively correlate with the size of area used by producers and the results of a chi-square test show that cropping period are, as can be expected, positively correlated to fallow lengths over the entire data; for producers who have longer fallow periods tend to have longer cropping periods.

Interviews with Charles Lui revealed there is a distinction in the island's customary land tenure system between private and tribal land. The main distinction is that private landowners decide to whom their land will be passed on to whereas tribe members make that decision for tribal land.

Table 5. Summary of t-test results conducted on collected data and concomitant p-values for differences in agricultural practices and land ownership across clusters of producers. If results between stated clusters are significant, the two averages are indicated. If averages do not differ significantly across clusters, the global average is given.

	Number of plots		Size of plots (m^2)		Total land (m^2)		Fallow length (years)		Cropping period (years)	
	Mean	P-value	Mean	P-value	Mean	P-value	Mean	P-value	Mean	P-value
Population density:										
Low	4.0	0.37	1570	0.01	6000	0.0042	5.3	0.016	2.5	0.26
High			630		2200		3.8			
Age of islander:										
Younger	4.0	0.063	1305	0.22	5000	0.37	4.6	0.26	2.5	0.28
Older										
Size of farmed area:										
Smaller (<0,3 ha)							3.8	0.019	2.2	0.020
Bigger (>=0,3 ha)							5.9		2.7	

Collected data during the workshop shows that approximately 72% of the population relies on both private and tribal land to produce food whereas 17% rely exclusively on private land and 11% exclusively on tribal land.

Historically the island's territory was split amongst the three first tribes to conquer it, thus all land was tribal. When an individual seeks to purchase land for himself, he approaches tribe members with his demand and they settle on a price of transaction, the transaction is then remembered or, in some cases, written down to be remembered. It is the role of certain tribe members to act as living memories; they are given a tribal role close to that of a magistrate, responsible for land conflict resolution. The passage of private land from one hand to the next always requires payment and the sum depends on the bond between the two members of the deal: "The price depends on how much you love the other person" (C.H Lui). Money is not the only currency of these transactions; the price is often completed with customary crops and/or a pig. Some clans or households have more land than others, this inequality of land distribution occurred when tribes first got to Sandfly, as warrior minded tribes and clans conquered bigger territories and as chiefly families amongst tribes established themselves as owners of bigger parcels.

Land is not a right of birth and is not part of heirloom. Hence some situations occur where newly married couples find themselves without land neither to settle on nor to crop. The couple may then approach parents or relatives, big landowners or their tribe to ask for land.

Land dispute is regular and often involve more than two parties, as record of land ownership changes is not centralized. Depending on the size of the case and the parties implied, it can be brought to different levels of jurisdiction: the community house of chief groups with the village chiefs, the district house of chief groups with all chiefs from the district, Gela house of chief groups with all chiefs of the Gela Islands (has been absent for several decades), and finally it can be brought to a official magistrate. Customary law being recognized as a source of law by the Solomon Islands Constitution of 1978 (Futaiasi, 2011).

Table 6. Types of crops and percentage of respondents who grow them in their gardens : Results of the survey conducted during the workshop in Siro .

Crop type	**%**
Banana	100
Slippery kabis	100
Pana	94
Yam	94
Kumara	94
Cassava	94
Eggplant	94
Beans	94
Tomato	89
Pumpkin	89
Taro	83
Papaya	83
Pineapple	83
Ginger	72
Chili	72
Peanuts	61
Melon	56
Sweet pepper	33
Chin. Cabbage	28
Cucumber	22
Corn	20
Sugarcane	20

The length of the period during which a garden is cropped is determined by soil fertility as the most nutrient demanding staples are planted first; these are pana (lesser yam, *Discorea esculenta*) and yam (greater yam, *Discorea alata*), they both have growth periods of 7-8 months and although these are seasonal crops in most places, they can be cropped all year round in the Central Province (AusAID, 2006). Most of the tubers from the first harvest serve as planting material for a second cycle, some tubers are replanted on the same plot, and some serve to plant on a newly cleared plot where the same crop succession will start over. After the second pana and yam cycle, a third and sometimes fourth one might follow depending on obtained yields. Once signs of declining fertility are observed, crops with a lower nutrient demand and shorter growth period of 3 months follow. These are kumara (sweet potato, *Ipomoea batatas*) and cassava (*Manihot esculenta*) and taro (*Colocasia spp.*). The plot is usually cropped until yields drop and it is time to let the plot fallow to rebuild fertility.

Diets also rely on leafy greens: slippery kabis (*Abelmoschus manihot*) is grown at any stage of the succession in gardens whereas Chinese cabbage (*Brassica sp.*) is either grown like slippery kabis or closer to households on planting beds or closely monitored gardens. Pumpkin shoots and watercress (*Nasturtium officinale*) are eaten too. Grown vegetables are tomato (*Lycopersicon esculentum*), eggplant (*Solanum melongena*), pumpkin (*Cucurbita moschata*), sweet pepper (*Capsicum annuum*), cucumber (*Cucumis sativus*) and beans (*Phaseolus sp.*).

Fruits are grown all year long around the garden and in fallow areas: pawpaw (papaya, *Carica papaya*) and bananas (*Musa* cultivars- can be either cooked green as starchy staple (plantains) or consumed sweet as fruit and snack) grow all year long and, depending on the season, pineapple (*Ananas comosus*) and melon (*Citrullus lanatus*) serve as food and cash crop while forest products complete the diet: mango (*Mangifera*), soursop (*Annona muricate*), five corners (*Averhoa carambola*) as well as some local nuts like the ngali nut (*Canarium indicum, Canarium salomense*) and cutnut (*Barringtonia sp.*). The coconut (*Cocos nucifera*) is used daily by most households for all forms of cooking, for drinking, and for sale. (AusAID, 2006)(AusAID, 2006)

Cash crops include ginger (*Zingiber officinale*), sweet pepper (*Capsicum annuum*), sugarcane (*Saccharum officinarum*, also consumed as snack food) and peanuts (*Arachis hypogaea*). All staples, leafy greens, vegetables, fruits and nuts, serve as fresh produce marketable goods at any time of surplus and are commonly sold on local markets or Honiara central market when transfer is organized.

Pana, yam and taro have a high cultural value, they are highly embedded in local culture and are to be served in all customary ceremonies like marriage, funerals and festivities. Pig meat is equally of utmost importance in such occasions.

Many households are smallholder livestock owners, pigs and poultry exclusively. Pigs are fed on kitchen waste and are kept in small pigsties or leashed to a tree, chicken are free range. Sandfly relief provides little flat area and most of it is dedicated to villages and coco, sago and areca palms plantation; Sago palms (*Metroxylon spp.*) provide leaves for thatched roofs, *Areca catechu* provides timber for houses and the customary chewed Betel nut. Bigger timber for house beams and structures is found in the denser forest, typically where slope makes agriculture too trying. Many gardens are cleared on hillsides where slopes can be as steep as 40° and soil erosion highly constraints production. Flat plots are scarce in agriculture and data from the interviews shows that a third of the population has access to one flat plot in their rotation, 17% has more than one, and roughly half does not have access to flat areas for farming purposes. Grasslands are of little use and are regularly burnt down to avoid overgrowth and to ensure walking through them remains easy.

This type of agriculture is of very low/no input, crops are 100% rain fed and no chemical fertilizer or pesticides are used.

4.2 Pressures on the system

Population growth and intensification

Allen et al. (2006) estimate that the current land use has an R-value of 45, described as a "reasonably high level of intensity". Collected data shows that R-values vary across the island and that islanders from densely populated villages from the Leitongo district have a significantly higher average R-value (p-value= 0.0014) of 43 (sd= 11.6; n= 26) compared to the less densely populated villages of the Ravu district, displaying an average R-value of 34 (sd=7.7; n= 25). In effect, they share the same average cropping periods of 2.5 (sd=0.5; n= 7) years but have significantly different fallow lengths as is reported in the previous section (Table 5)

Allen *et al.* (2006) write that villagers of Sandfly Island pointed at declining soil fertility as the main constraint to subsistence agriculture, pushing some farmers to crop the less fertile grasslands. This observation was made by Allen *et al.* (2006) in Olevuga and can be extended to Leitongo and Tubila, but not to the rest of the island where population is still low enough to avoid such pressure on land: producers prefer to find proper brown soil to use as arable land within further walking distance rather than crop close by grassland yellow soils.

Though at different degrees, intensification is on its way all around the island: respondents from every visited location agree to say that fallow periods were closer to 15 years in the time of their parents, for older people; and grand-parents, for younger people. Others would describe that regeneration on fallow plots used to bear tall and thick trees before they were brushed and cropped whereas nowadays, only low woody regrowth cover them, sometimes even only grass. Peter Mike, paramount chief of Gela, stated in an interview that over his lifetime fallows have grown shorter and less food is produced from gardens nowadays compared to yields of previous generations. He linked that to the heavy population increase and small land availability of Sandfly Island, saying that land availability would become a serious problem in the coming 10-20 years. Notable effects of intensification are seen on Sandfly: the prevailing grasslands of the hilly interior are ascribed to over-intense cultivation and burning in the past (Allen *et al.*, 2006). Secondly, the fact that most villagers from the Leitongo area have translocated part of their agriculture to faraway places, like Tahimate or even Small Gela the neighbouring island, describes the unavailability of land around high population density villages. Thirdly, as custom wants that crops from the first harvest be blessed by the local priest, Josef chief of Sodulu has reported a witnessing of declining sizes in harvested tubers; Steven of Sodukosi complained of decling sizes in harvested pana. Additionially, answers given during the first group discussion of the organized workshop, where particpants were asked to identify major changes in the food production context over the last 30 years, show that islanders have perceived a decline in quality of harvests, a shortening of fallows and a decline in land area per inhabitant. Finally, several respondents indicated that people have to clear smaller gardens to guarantee a reasonable fallow length for their other plots under fallow.

Local adaptations include the use of bat guano to fertilize high output vegetable gardens, mulching with crop residues, reducing garden size to reduce pressure on available land and for one special case, changing land use to non-shifting agriculture with mulching as a source of fertilizer. This case is studied in the lower section “The case of Charles Lui”.

Climate change

As mentioned in the introduction, climate change is an on-going reality for producers of the Solomon Islands. Some changes are already on their way and recorded ‘anecdotal evidence’ of this is numerous on Sandfly Island. 76% of people who were asked about it knew of climate change though only 74% of those could explain what are its effects on their environment. While many islanders confuse climate change for seasonal variation, some notable testimonies are to mention: Simon Kikoa from Leitongo 2 reports an extended drought that came in 2019 during the dry season, many root crops died because of it, he attributes this unusual extended lack of rain to climate change. Clement Kili from Leitongo 1 observed coastal erosion and degradation attributed to sea level rise, aggravated by the gradual destruction of mangroves for harvesting wood. Francis Durai from Leitongo 1 has observed a disturbance in the global wind patterns. Michael Kouma from Leitongo 1 has witnessed soil erosion and landslides because of more violent rains and talks of streams going dry when they used to keep running before. Vincent Usi from Boroni concludes that gardens do not bear as high yields as before because of climate change and worse weather conditions. Steven, an elder from Ravu Sodukosi complained of an unusually violent rain event in 2017 that caused a landslide in his gardens resulting in the total loss of harvest from two plots. He describes that sea levels have risen in such a way during his lifetime that the coast has retreated by several meters, pushing back the coastal village zone to where the bush used to stand and relocating gardens higher up the slopes. During the group discussion that took place at the organized workshop, participants agreed to say that weather conditions have become unpredictable over the last 30 years, creating harder conditions to grow food and a general drop in food security.

4.3 Adoption of innovations

The case of Charles Lui

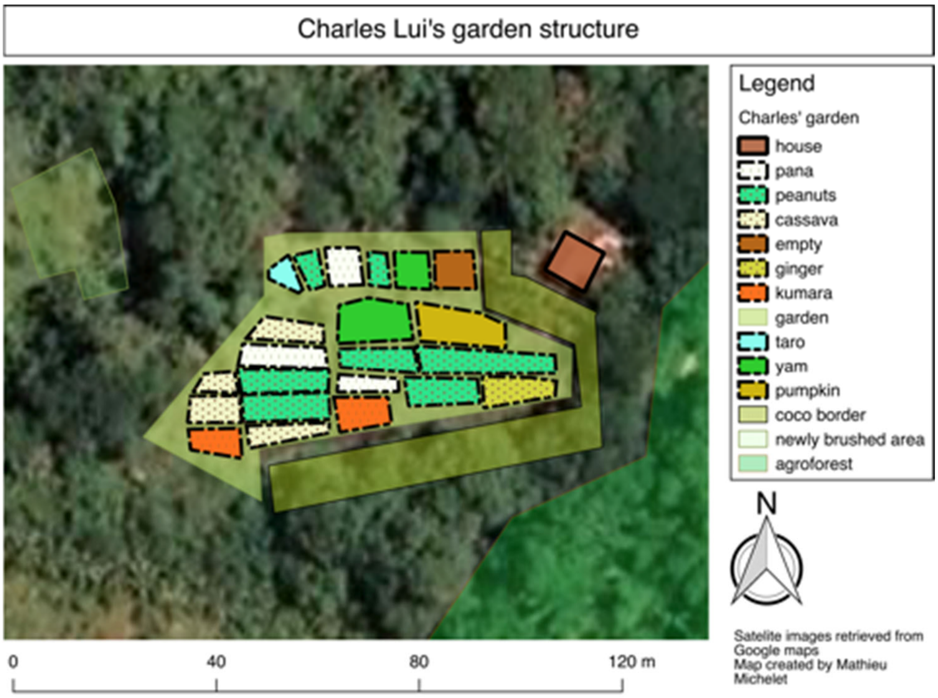

Figure 13. A representation of the structure of Charles Lui's garden in 2020. Satellite images retrieved from Google maps and modelling done by Matthieu Michelet

In the agricultural landscape of Sandfly Island there is one unique exception, this case gives an example of a farmer who has decided to change to adopt a different farming style on Sandfly Island.

In his young age, Charles was given the opportunity of pursuing education to a higher level thanks to his remarkable performance in school and thus, was given a government scholarship. His education led him to work for the ministry of education for several years but, for personal reasons, he decided to leave the sector to come back to a more traditional way of living on his home island, and he settled on a piece of private land in the eastern bay of Sandfly Island with his wife Margaret. During a workshop organized by KGA in Honiara, he decided to change his way of subsistence to fit a non-shifting agriculture model. He was convinced by the opportunity of providing enough for his family, to be able to farm next to his house and avoid the long usual walks to the far away gardens when the closer ones are in fallow. To the day this study is written, he has been doing so for 26 years on the same piece of land.

His garden varies in size in function of the availability of planting material; in February 2020 it was roughly 0.4ha (4000m^2). As it is illustrated in Figure 13, the area is organized in parcels of approximately 150m^2, demarcated by living fences of pineapples, dotted with banana and papaya trees and surrounded by borders of coco trees and betel palms near the house while sago and betel palms growing amongst naturally occurring tree species surround the rest of the area. In the different parcels he organizes a rotation of pana, yam, cassava, kumara, ginger, peanuts, pumpkins and slippery kabis of multiple varieties with monthly mulching as the only input.

The rest of his land is managed as a semi-wild agroforest with many sago and betel palms that provide timber and thatch for houses; fruit trees like mango, five corners (*Averrhoa carambola*), soursop (*Annona muricata*), watery rose apple (*Syzygium aqueum*), nut trees such as the Ngali nut (*Canarium indicum*) and plenty other species providing a variety of services and resources.

Charles and Margaret's children have all left the house and the couple, both in their fifities, work in the garden together with an impressive dedication, following customary man-woman division of the workload. The area bears abundant yields and help not only to feed the couple but also the frequently visiting friends and family members who, by custom should receive food for the journey back home. This custom has been twisted in a way that most people see it as a right to help themselves in others' gardens and forest when visiting, especially when these are known to produce much. Charles and Margaret make use of more intense agricutlural practices and therefore have a higher labour input and thus a higher total output. Data on yield levels were not collected so output per labour input levels could not be compared.

Charles has well chosen the place and his system of land use is tailored to appropriately make use of local conditions. The area is mostly flat and its black soil is one of the most fertile of the island. To better estimate the impacts of such a farming on soil fertility, two soil pits were sampled and analysed : the first pit is situated in Charles' garden, on the plot closest to his house and has thus been cropped for 26 years, the other pit is in a freshly cleared parcel of bush and is thus representative of the surrounding soils' natural fertility. Results are given in Table 7 where one can see that over the course of 26 years of cropping SOC, total N and plant-avaiable P stocks have been reduced by 30 to 50% in average while base saturation, CEC and K$^+$, Mg^{2+} and Na$^+$ levels have stayed the same and Ca^{2+} contents show an accumulation.

Despite the little significance of results of such soil comparion, because of the absence of replicates that could have led to a statisitcal analysis, results show that the output of nutrients through harvest, erosion, leaching and gaseous losses is bigger than the input received by the soil through the monthly mulching. To compensate with the pressure on his most used plots, Charles occasionally clears new plots from the surrounding bush to plant his more valuable and nutrient demanding crops while older plots, like the sampled plot described above, are used for cropping peanuts, ginger or might be left unused for some time to regenerate fertility. To further improve his system, Charles could make use of legume trees to provide N-rich mulch, increase the use of

Table 7. Results of soil analysis, comparison of Charles Lui's garden soil and the surrounding bush's soil at 2, 15 and 40cm. The change in fertility parameter levels over the 25 years of cropping the garden soil is given in percentage in the column « Change ».

Depth (cm)	2		Change (%)	15		Change (%)	40		Change (%)
	Bush	Garden		Bush	Garden		Bush	Garden	
CEC (cmolc/kg)	1.2	1.3	+8.3	1.3	1.2	-7.7	1.4	1.5	+7.1
BS (%)	49	46	-6.1	43	50	+16.3	40	40	0
SOC (% of weight)	8.0	4.5	-44	4.3	1.5	-65	1.0	0.6	-40
TN (% of weight)	0.63	0.39	-38	0.37	0.13	-65	0.09	0.05	-44
P (mg P/kg)	15.2	8.4	-45	3.3	2.4	-27	0.12	0	-100
K (cmol/kg)	0.11	0.07	-36	0.04	0.05	+25	0.04	0.04	0
Ca (cmol/kg)	0.08	0.15	+187	0.09	0.16	+78	0.11	0.15	+36
Mg (cmol/kg	0.28	0.28	0	0.29	0.30	+3.4	0.32	0.31	-3.1
Na (clom/kg)	0.12	0.11	-8.3	0.12	0.10	-17	0.11	0.12	+8.3
Exch. Ac. (cmolc/kg)	0.62	0.72	+16	0.72	0.60	-17	0.86	0.92	+7.0

legumes in his crop rotation, make use of green manure, use compost as a nutrient input or increase intensity of mulching. When faced with this, he commented that a wheelbarrow would help him a lot as he is physically limited in the amount of mulch he can currently apply without tools.

Charles has been interested in agriculture since primary school and his long-term engagement in his land, thanks to his land use system, gives him the space and time to innovate. He is continuously trying out new techniques or conducting field experiments to observe output reactions to management practices. This aspect is essential as he does not follow guidelines by the book but rather attempts to find the most appropriate techniques for local conditions.

Success of past extension efforts

The case of Charles Lui shows that the population of Sandfly Island is subject to previous extension efforts and people have heard of a different way of producing food. Many know Charles Lui and many visitors have observed his non-shifting agriculture model; furthermore, the high school in Siro provides a course in agriculture for students where they learn about composting, mulching and other innovative intensification practices to improve subsistence.

Through data collected during the interviews, the following section outlines how knowledge about agricultural innovative intensification practices is spread throughout the population of Sandfly Island and what are the adoption rates and effectiveness of past extension efforts.

All results refer to composting and mulching as key innovative intensification practices. Data shows that 63% of interviewed farmers know of mulching and composting, while 25% of those who know about them apply such practices. From this group of 25%, 60% use crop residues to mulch after harvest, a practice somehow embedded in local custom thus not evidence of adoption of new innovation. The other 40% (5 people so 8% of total interviewed people) show true adoption of new innovations and have adopted an improved shifting agriculture model: Irene Kaleva from Olevuga uses bat droppings to fertilize her vegetable gardens, she applies mulching and composting in her root crop gardens; Peter Pelo, Joseph Keba and Michael Koumu from

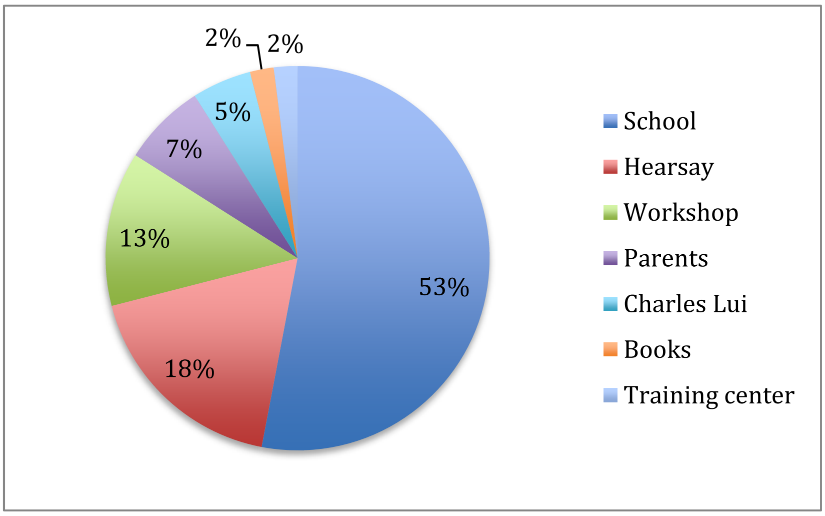

Figure 14. Rates by source of knowledge of mulching and composting amongst interviewees on Sandfly.

Leitongo 1 and 2 apply mulching regularly on their gardens, Robert Irara from Leitongo 1 has adopted brush and hoe; two other interviewed producers declared they used to mulch regularly their gardens but the first stopped because it represented too much work as he got older, the second stopped because it asked for too much work and he thinks he needs more guidance.

Figure 14 shows interview results on the variety of sources from which interviewees have learnt about innovative intensification practices, school is the most far-reaching source as more than half of interviewees had learnt from school. Adoption rates vary from source to source, results show that he most efficient way of transmission on Sandfly appears to be from parent to child as 100% of interviewed farmers who had learnt improved gardening skills from their parents were either currently applying them or used to at a younger age despite having to stop because of age. The rate of adoption for school and workshops is respectively 9.5% and 20%. One out of the two interviewees who had learnt of these innovations from Charles Lui has adopted mulching. All producers who have effectively adopted innovative intensification practices come from the Leitongo district; 2 of them are big landowners while the other three have normal sizes of available land area for agriculture. They all share the characteristic of being much involved in

Table 8. Results of interviews, stated reasons of non-adoption of mulching and composting and comparison across clusters of producers and in function of extension source. Results are given in percentage of studied group and in number of concerned interviewees

Reason	Need advice and guidance	Not enough knowledge	Goes against custom way	Too much work or lazy	Need help or tools	Need more land	Sceptical	Number of interviewees
General (%)	58	44	23	23	9	5	5	
n	25	19	10	10	4	2	2	62
Ravu district	56	32	24	32	16	0	4	
n	14	8	6	8	4	0	1	28
Leitongo dist.	61	61	22	11	0	11	6	
n	11	11	4	2	0	2	1	35
Small landown.	71	57	57	0	14	0	0	
n	5	4	4	0	1	0	0	11
Big landown.	57	29	14	50	21	0	0	
n	8	4	2	7	3	0	0	16
School	77	33	27	33	27	7	0	
n	11	5	4	5	4	1	0	21
Workshop	25	0	25	75	0	0	0	
n	1	0	1	3	0	0	0	5
Hearsay	80	40	40	0	0	20	0	
n	4	2	2	0	0	1	0	7

community life either as village chief, provincial community officer, voluntary worker or schoolteacher. Three out of the five are educated farmers.

Those producers who have been targeted by extension programmes and thus stated to know of innovative intensification but decided not to adopt were asked about the reasons of non-adoption. The results are given in Table 8, *nota bene* numbers do not add up to 100% as 53% of interviewees gave more than one reason for non-adoption. Adoption rates are given amongst a population of potential adopters that encloses all producers who have been reached by extension.

When breaking down reasons of non-adoption per source of knowledge, big differences appear especially in the need for more advice and guidance, knowledge and the load of work the innovations' adoption represents. Indeed, those producers who have learnt from a workshop have a higher tendency to perceive the innovation as a too high workload though have a smaller need for guidance or further knowledge than those producers that have learnt from school or from hearsay. The statistics for producers who think the adoption goes against custom is quite homogeneous though higher amongst producers who have learnt through hearsay.

When comparing the reasons of non-adoption across clusters, some differences can be observed: producers from Ravu mention the argument of laziness or of too much work significantly more than producers from Leitongo (p-value = 0.043); big landowners mention that argument significantly more than small landowners (p-value=0.0037). The argument that adoption goes against custom way is homogeneous across clusters of producers; the need for knowledge and guidance and advice is homogeneous across districts though big landowners mention that need significantly more than small landowners (p-value= 0.038). There are no significant differences across producers of different age classes.

Picture 3. Charles Lui and Margaret in front of their house. Picture by M. Michelet

5. Discussion

5.1 Soils and bush fallow

The different soils of Sandfly can be grouped in different classes:

- High inherent and dynamic fertility:

Both black and brown soils display similar levels of CEC, BS and EBC but are distinguished by a difference in total N, plant available P and SOC as the brown soil shows high levels of P but lower levels of TN and SOC compared to the black soil, though still satisfying. Both brown and black soils are spoken of as black soils by islanders and they are undoubtedly the most fertile soils of the island, though the steeper the slope on which they have formed and the higher up in the hills they lie, the more prone they are to erosion and to loss of topsoil and therefore to a limited fertility.

- Low inherent and high dynamic fertility

The sandy soil displays low CEC, as can be expected of a sandy soil but surprisingly, high levels of SOC down to deeper levels contributing to high levels of N and P. Additionally, though having low levels of BC, it has a high base saturation, certainly due to the alkaline pH, playing in favour of a relatively fertile soil. pH and soil texture create a limit to the soil's potential as water retention is consequently bound to be low and drainage high; thus it can be concluded that the island's sandy soils have a low inherent fertility but can be managed to build a high dynamic fertility.

- High inherent and low dynamic fertility

The yellow soil has generally low nutrient availability, when it comes to N and P, mirrored by an average SOC, certainly due to high surface wind and water erosion. Despite this, the soil shows promising levels of base cations, base saturation and an optimal neutral pH; it might be improved with the correct management approach in order to build up SOC. If the right conditions are created, there are reasons to believe that the yellow soil can be improved to resemble the brown soil as the latter is formed on the same parental material, has similar chemical properties but, due to a position more sheltered from wind and rain erosion, has developed more appropriate levels of SOC, TN and plant-available P which initiates a positive feedback loop as supported ecosystem develops.

- Low inherent and dynamic fertility

The red soil has a too acidic pH to be considered as fertile. The consequent low levels of N, P, and SOC show the impacts of soil acidity and even though CEC is higher than the other soils, most of its charges are occupied by acidic cations, reflected by the very low BS.

This analysis shows that there is variability amongst soils on Sandfly Island because of a difference in parent materials and because of variability in TN and plant-available P levels that are intimately linked with SOC levels. Considering this average soil fertility, productivity can be expected to highly depend on a soil's SOM content and therefore on any phenomenon that either encourages SOM accumulation or loss such as fallow lengths and erosion. In this agricultural system of no external input, SOM is one of the only parameters producers can try to influence in order to obtain better yields. In this context, the systems of bush or forest fallow are, as stated in the introduction, appropriate and efficient ways to build up SOM, and thus soil fertility, and are adapted to local conditions.

The results of analysis match quite accurately local producers' perception of soil fertility. Nevertheless, producers' perception only gives an indication of relative variation amongst a local scale of fertility proper to Sandfly Island and does not observe the more global scale of fertility. Indeed, the black soil is more fertile than the yellow soil and thus is considered a fertile soil on Sandfly Island but when comparing the black soil on a world base, though it presents proper levels of SOC: levels of BS, CEC, TN and plant-available P are all quite low and it can be concluded that the black soil is only of intermediate fertility. Producers' perception is therefore accurate on a local base but requires further analysis to situate the perceived fertility on a more global scale.

5.2 Farming styles

Data shows there is variability between producers in terms of fallow lengths and cropping periods though trends are found between producers from the same area or between big or small landowners. Four clusters of producers can thus be established: firstly, producers from the Leitongo district where population density is higher who tend to have smaller plots, smaller farmed areas and shorter fallow periods, due to land unavailability producers from the first cluster might make use of yellow or sandy soils in addition to the usual black or brown soil. Secondly, producers from the Ravu district where population density is lower, who tend to have bigger farmed plots and thus greater farmed areas and longer fallows, they make use exclusively of black or brown soil; thirdly, big land owners who occur in both districts, though dominantly in the Ravu district, and who tend to have the longest fallow periods and cropping periods, they make use exclusively of black or brown soil. Fourthly and finally small landowners who occur in both districts though dominantly in the Leitongo district, who tend to have shorter fallows and cropping periods.

These clusters are built around producers who share the same constraints to production as to expectedly have a similar attitude towards the adoption of the same innovations as is stated in Farming Styles theory/ The two first clusters are shown to have the same average number of plots in their agricultural rotation but producers of the first cluster have smaller agricultural plots. This shows that producers from the first cluster suffer a higher constraint to production because of land unavailability. The second cluster nevertheless perceives a pressure of land unavailability as they are also affected by declining yields. The third cluster groups a small minority who has no other environmental constraints than those common to all producers due to the context of Sandfly Island: a reduced access to market, poor transport infrastructures, low market opportunities. They might come to share the constraints of the two first clusters though as they are often solicited to share surplus of land with those who have a shortage.

These clusters are not mutually exclusive.

5.3 Demographic rise

Collected data points out to an agricultural intensification in the past decades: where land used to be under forest fallow with fallows averaging 15 years, actual fallow lengths and regeneration vegetation indicate that land is now used under the system of bush fallow in less populated areas and that in the more densely populated places fallow lengths even fit the definition of short fallow though agricultural practices are overall the same across the island. This intensification has mainly happened in a non-innovative way (Laney, 2002) by shortening fallow lengths and reducing garden sizes but very little innovative intensification has taken place: fire is still a central technology to clearing fallows, sticks are used to locally hoe ground and the introduction of the machete and of new short cropping-period staples like kumara and cassava by colonizing Great Britain during the 20th Century (Laracy and Foster, 2020) appear to be the only innovative intensifications.

Even though the total system output has obviously increased as more food is produced from the same area, individual household yields do not follow the same trend. In fact, testimonies indicate individual yields are going down. Understandably, as Boserup (1965) points out, other ways of preserving or regaining soil fertility must be introduced when fallows are shortened. In Sandfly's case, the introduction of low nutrient demanding crops has contributed to stabilize food security, despite the increasing land degradation and declining agricultural productivity but such innovation, though helping to reduce pressure on land is not a solution to the long-term problem of declining fertility (Grayson, 2002).

Results confirm the view of Boserup (1965) as agriculture is shown to be intensifying especially in places of high population density though, interestingly enough, much of the local testimonies reporting a decline in harvest and tuber sizes come from the Ravu district where population density is lowest. This points out that, though less marked in some places, the pressure of demographic rise involves both producers from the Leitongo and Ravu district, i.e. producers from the first and second clusters established earlier. Non-innovative intensification (i.e. shortening of fallow, extension of cropping period, reduction of garden size) can serve as a temporary solution to the increased pressure on land but the fate of the grasslands of the hilly interior serves as an observable possible outcome for ecosystems and soils if such pressure is maintained for an extended period. Examples from other islands such as the case of Loun (Russel group, SI) where soil fertility, because of agricultural intensification, has declined to such an extent that even cassava is no longer growing well (Bourke *et al.*, 2006b) amplify the indispensable requirement for farmers to adopt innovative intensification practices. In the opinion of the paramount chief of Gela Peter Mike this should happen in the coming 10-20 years, to effectively help stop or reverse the down-spiralling trends of soil fertility pointed at both by literature and the results of this study. This situation is even more urgent for producers of the Leitongo district i.e. producers of the first cluster.

5.4 Climate change

The different soils of the island will be affected in different ways and to various degrees by such changes in conditions. Indeed, the black soils' value could increase in the dry season as they have generally high SOC, and thus, water retention, and due to their situation in areas with high water tables, water stress might be less severe. This property turns to a disadvantage during the wet season when it might lead to increased risk of root rotting especially because of bad drainage. Despite these aspects, their geolocation on the margins of the island in flat coastal areas make them much vulnerable to sea level rise and salinization; in the long run, they will come to be useless for agriculture.

For brown soils that are mostly present in sloping areas, the higher threat is increased water erosion. The increased production of OM, thanks to new climatic conditions that boost photosynthesis as mentioned in the Introduction, will help maintain soil structure; a management that helps mitigate water erosion will therefore doubly benefit farmers, as it would obviously decrease erosion but also help build up OM that will improve soil structure. The yellow soil's dynamic fertility will continue to be limited by water and wind erosion but if management is adapted to reduce the latter two, dynamic fertility is expected to build-up faster and reach higher levels in a way that hopefully could open them up to production. The sandy soil's high drainage discards it from potential use during the dry season but gives it great value in the wet season when most soils in flat areas risk flooding due to the heavy rainfall. The expected increased OM inputs, will improve dynamic fertility. Unfortunately, its coastal geographical distribution makes it highly subject to salinization in the long term. The red soil is not considered because of its small spatial distribution.

Where pressure on land due to population rise most importantly affects those producers from most populated areas, the pressure of a changing climate is an environmental constraint to production affecting all clusters of producers equally. Despite this all-enclosing involvement of the impacts of climate change, one can expect producers to integrate more easily the problem of demographic change in their decision-making for it has a direct and more visible impact on production efficiency and food security. On the contrary, climate change is still a distant, misunderstood reality for many. Indeed the climate change problematic is subject to temporal, probabilistic and spatial distancing.

Temporal discounting is the phenomenon by which the subjective value one gives to a good or commodity tends to be reduced over time; in other words, an outcome delayed in time will most often intuitively be considered less valuable than an outcome that can be obtained presently, even if economical sound thinking would prove the contrary. A study by Hardisty and Weber (2009) has shown that environmental outcomes were discounted in the same way as monetary ones and through further studies, Sargisson and Schöner (2020) have come to show that people tend to build a psychological distance towards events in function of the probability at which the event is expected to happen, the distance from them at which it will happen and in how long it is expected to do so; and that one's willingness to act upon it or to experience concern undergoes probabilistic, spatial and temporal discounting following a hyperbolic trend. Simply put, people tend to favour outputs that happen now, here and for certain than outputs that might happen somewhere else in a certain time. The willingness to act to build resilience to climate change is thus more temporally and probabilistically discounted than the willingness to act upon the need to build sustainability because of aggravated pressure on land due to demographic rise.

5.5 Appropriate Innovative Intensification Practices

Literature shows that rain distribution is grouping in peaks of higher intensity, increasing violence of rain events and decreasing overall water availability; temperatures are rising as to increase evapotranspiration; the intensification of agriculture in high agricultural value land causes yields to decline and production is pushed to low agricultural value land where factors such as slope or soil fertility highly constraint productivity; general pressure on land is rising with population, population continues to increase and land is expected to become less available because of sea level rise. These facts are presented in literature and confirmed both by collected interview data and local witnesses. Based on such facts, some recommendations can be made to build a vision of an appropriate land use on Sandfly Island to protect subsistence agriculture, ensure its long-term sustainability and build up both system resilience in the face of climate change, population rise and household livelihood resilience in the face of local economic variability.

The general soil status of a low CEC, low P and K but also the continuous pressure of soil exposure to erosion as it is repetitively laid bare by fire fallow clearing, give great opportunity value to agricultural practices that can help break the down-spiralling of soil fertility by a series of effects on soils and system. This should be achieved by ensuring topsoil build-up, reduction of soil nutrient and topsoil losses, a closing of nutrient cycles, input of organic matter to consequently not only bring nutrients into agricultural systems but also contribute to creating a healthy living soil with a breathing structure and a sustaining clay-humus complex that vouches for a better soil moisture retention and soil resilience. Collected testimonies show that Sandfly Islanders agree to say that the limits of traditional system of fallow as the only technology of soil fertility restoration have been reached; in current conditions of population and land pressure, it is becoming more destructive than beneficial and thus obsolete. The use of these practices such as mulching, composting and contouring, if spread-out, can benefit producers in two ways.

The first is that they offer the possibility of conceiving rehabilitation of the low agricultural value grasslands of the hilly interior and thus increase arable land area, which would contribute to lifting pressure on cropped land. As pointed out by Jansen *et al.* (2006), their rehabilitation could open them up for agriculture or more probably, agroforestry. The main focus to achieve such a goal should be brought to refraining erosion and allowing the yellow soils supporting the grasslands to build up organic matter and consequently dynamic fertility. Guta (*Morinda citrifolia*), mango (*Mangifera*) and gliricidia (*Gliricidia sepium*) are all trees that can grow in the current low fertility state of the grasslands, as local field tests made by Charles Lui show positive results. By implementing a permanent vegetated contouring in the flatter areas of the hilly interior with these species, it will initiate a positive feedback cycle of soil fertility improvement while at the same time producing goods used either as marketable in times of prosperity or as emergency food in times of hunger. This process requires little monitoring or management and builds up fertility potential than can then be released in various ways. On-site field tests should be done to assess whether other valuable tree species (nut or timber varieties) can grow in the improved conditions once they are established with the initial cover or even better, in the current low fertility conditions. Legume trees are expected to play an important role in this N-poor environment through their ability to biologically fix atmospheric di-nitrogen. Opting for tree stands of only legume trees can be economically interesting in the long term as they provide the possibility of growing vanilla in the understory. Vanilla production is a fitting cash crop for the low nutrient environment of the grasslands (Jansen and Maike, 2010) though requiring high monitoring, management, skill learning and tool demand; it is a very complex type of production. When well managed, the hilly interior can be expected to come to provide sufficiently good conditions for agriculture or for other tree cash crops like cocoa.

The second opportunity is that of strengthening subsistence by increasing production's sustainability and resilience. Here below is a reflexion on the most appropriate innovative intensifications for the context of Sandfly Island producers, following the ideas of Schumacher (1973) about appropriate technology as a technology that will best serve those who will use it.

Mulching and adding organic matter

The simple technique of surface application of organic crop or tree residues can substantially improve and protect soil chemical, physical and biological properties. Literature review done by Döring (2004), summarizes the effects of straw mulching on soils as increasing soil moisture, decreasing and stabilizing soil temperature, drastically reducing run-off and soil erosion, moderately increasing soil organic matter contents, having variable effects on soil N in function of soil moisture and temperature and finally, increasing numbers of various soil biota and earthworms.

While global impact on yields is hard to measure and depends on local conditions and varieties, studies from the Kingdom of Tonga have shown that thick vegetative mulch could increase taro (*Colocasia esculenta*) yields by 81% and decrease soil erosion by 50% on sloping land, compared to local farmer practices (Manu, Whitbread and Blair, 2018). In studies conducted in a broad variety of climatic and soil conditions, it was shown that mulching improved water use efficiency, nitrogen use efficiency and yields were significantly increased by up to 60% for wheat and maize (Qin, Hu and Oenema, 2015).

For Sandfly Island producers, mulching represents the opportunity of a free fertilizer to intensify agriculture sustainably while at the same time providing protection against wind and water erosion, rain slaking, soil surface crusting and sealing, thus developing resilience against climate change. KGA recommends a garden organization where crops are planted on raised beds and mulch is applied between rows; after harvest, positions are inverted and the second crops are planted where the mulch was previously applied and new mulch is spread where previous raised beds were situated. In this fashion, mulching benefits are maximized while rotting and pest outbreaks possibilities in the wet season are minimized (Live&Learn Environmental Education, 2011).

For fertilization practices to be most efficient for Sandfly Island producers, they must provide those nutrients that are the most limiting to production. In the case of every analysed soil type, K^+ concentrations are low and most certainly present the most limiting factor to production; natural important sources of K^+ are banana peels, bat guano, wood ash and seaweeds (Tutua and Jansen, 1994): to overcome K^+ deficiencies, such products can be added to the mulch or composted first before being applied in gardens. Nitrogen and phosphorus levels are equally low in general amongst soils and production can be expected to benefit greatly from such fertilization. Legume plants as mulch are of particular good use to help cope with N deficiencies.

In islands of the Solomon Islands, mulching is usually done with grass, leaves and other plant material from producers' immediate surroundings. Because cattle are so rare, the material used as mulch finds little other use. Indeed, the only livestock of Sandfly Island, i.e. pigs, are fed with organic waste from kitchens.

Contouring and permanent vegetative contours

Some local adaptations help to cope with the heavy soil erosion undergoing in the farmed sloping areas of Sandfly Island. On heavily inclined plots, farmers traditionally plant a row of banana trees across the slope half way in the length of the garden; rows of crops are planted along the slope and fell trees are placed between the rows.

To further improve this practice, rows of crops should be planted in contouring, across slopes. Depending on the slope of the garden of focus, soil water erosion can be decreased to the extent of reducing annual soil loss by up to 86% (Xiong, Sun and Chen, 2018), helping to keep topsoil fertility on site and increasing soil water content; for strongly sloping areas, crop contouring is not enough and might expose crop rows to landslide. In such a case, permanent contours should be planted with either crop or legume trees or grass strips to initiate a breaking down of the slope in natural terraces and encourage build up of SOM.

Brush and hoe vs. slash and burn

Slash and burn is used to relocate to the soil those nutrients trapped in the aboveground vegetation after a fallow period. Studies have shown that, in fact, the efficiency of fire in doing so is quite limited as it presents several disadvantages. First during the burning itself, C and N stocks are diminished by volatilization in almost parallel quantities varying between 30 and 90% depending on conditions; volatilization and convective losses also affect P stocks and even though cations have a higher volatilization temperature Ca^{2+}, Mg^+ and K^+ stocks can be affected (Giardina *et al.*, 2000). Secondly, a cleared plot where vegetation has been burnt down is highly exposed to both wind and water erosion as well as leaching of nutrients in case of rain: the finer fraction of ash is very susceptible to wind erosion and the wind erosion nutrient losses can be equal or even greater than volatilization losses (Raison, Khanna and Woods, 1985). In a comparative study, Giardina *et al.* (1985) find out that only 30% of N, 49% of P, 50% of Ca and 57% of K from the aboveground nutrient stocks are effectively returned to the soil as ash after burning. These numbers vary over climatic zones and do not take into account erosion, leaching losses or plant-availability of nutrients contained in the ash; the final efficiency of burning can be expected to be disappointingly low.

Furthermore, the burning of vegetation impacts the soil fertility in itself, both positively and negatively. The positive impacts are that the addition of ash tends to raise soil pH, this can be beneficial for acidic soils; the addition of ash stimulates microbial activity and heating of soil increases plant-availability of nutrients. However, heating of the soil has a destructive effect on soil fauna but also on soil C and N stocks; the extent of damages done depend on heating intensity and the resulting quantity of burnt biomass, and on length of soil exposure and soil characteristics like texture and water holding capacity. To conclude with the words of Giardina *et al.* (2000), burning can be expected to have significant impacts on the long-term nutrient balance of ecosystems.

In the case of Sandfly Island, agricultural productivity is shown to highly depend on SOM accumulation. The use of fire to clear fallows has been an efficient tool over centuries for such communities but alternatives exist that offer a higher efficiency in SOM build-up and could be of help in the situation of high agricultural intensity of Sandfly Island.

Slash and mulch, also called brush and hoe, offers a different approach to clearing fallows: rather than burning it, the aboveground vegetation is used as mulch. In this way, the problems of volatilization, erosion, leaching and heat damage from the burn are avoided. The warm and humid conditions of Sandfly make for a quick decay of fine tree and fallow residues, especially those with low lignin content and a low C:N ratio (Schlesinger and Hasey, 1981; Cattanio, Kuehne and Vlek, 2008) while bigger tree trunks and branches take longer, these can be used for contouring while they slowly decay, as firewood, or might me burnt off site and their ash spread on the garden with the mulch as a source of K^+. Studies of Kato *et al.* (1999), Sommer *et al.* (2004) and Cattanio, Kuehne and Vlek (2008), conducted in Amazonia, all three confirm that slash and mulch is a viable and sustainable alternative to slash and burn for a maintained agricultural productivity and ecosystem functioning and offering the possibility of intensifying agriculture while preventing the usually linked risks of soil degradation. Slash and mulch has proved to be efficient for other island communities of the Solomons (Live&Learn Environmental Education, 2011).

Use of legumes

Symbiotic N-fixation by legume plants is a great opportunity for low external input systems as it represents a free source of N-fertilizer. Some other communities of Melanesia make use of legumes in their agriculture either by alley cropping and agroforestry; by integrating legume crops in their crop cycles; or by planting legume trees to improve fallows. Available species of legumes include *Gliricidia sepium* locally called cocoa shade, long beans (*Phaseolus sp.*), winged beans (*Psophocarpus tetragonolobus*), peanuts (*Arachis hypogeae*) and cowpea (*Vigna unguiculata*) though only peanuts and bean varieties are generally spread-out amongst producers of Sandfly Island and they are rarely recognized as anything different than a traditional crop.

Farmers in Vanuatu plant Gliricidia or Erythrina (*Erythrina variegata*) in fallows to improve fallow efficiency in restoring fertility. After 2-3 years, the trees are ringbarked so that fine tree material is restored to the soil surface, providing a good quality mulch with low C :N ratio and lignin content, then trunks and thick branches are used as quality fire wood.

On Montmartre farm in Vanuatu, Gliricidia is used for alley cropping : 5m separate the alleys of trees that are planted 1 meter apart from each other. Trees are pruned regularly to avoid shading and to provide quality mulch to the strips of crops. Such a method can significantly prolonge the length of cropping periods : in the case of Montmartre farm, crops have been rotating for 10 years (yam – sweet potato – taro – maize) without fallow and yields have stayed economically viable without inorganic fertilizer input (Live&Learn Environmental Education, 2011).

In Mana'abu, Malaita, some farmers have integrated legumes in crop rotations in addition to legume trees alley cropping. Some legumes are planted for harvest while others are slashed and mulched when flowering to be used as green manure. This allows farmers to crop their gardens permanently rather than in rotation (Live&Learn Environmental Education, 2011; Tutua, Jansen and Logan, 2011). All of these examples can be followed on Sandfly Island, both on flat and sloping land, provided that certain legume species, especially trees, are spread around amongst farmers.

5.6 Aspects of innovation adoption

Many examples of different successful models exist for non-shifting agriculture or improved shifting agriculture in Melanesia and it comes down to individual decision and knowledge as to how to approach the challenge. As Charles Lui's case demonstrates, it is possible with innovations described above to conceive and apply new sustainable and resilient models of production on Sandfly Island that are economically viable and can respond to the higher demand in food coming from the local population increase. Indeed, these new models offer a higher output than the current system of land use though a required higher total labour input is unavoidable. Despite a higher labour input, some advantages can be gained in terms of physical labour, as the producer will consequently be spared the heavy work of clearing fallows or the recurrent walks to far away gardens. No clear measures of yields are made thus output per man-hour levels are hard to compare between systems.

Results show that a vast majority of the population has learnt of the practices explored above. Nevertheless, adoption rate is quite low and results show that the perceived relative advantage gained from adoption of such innovations varies from one producer to the next. Presented innovations share similar characteristics: they have a low complexity when it comes to their understanding and application as they generally consist of quite simple practices. Perceived complexity yet changes in function of the potential adopters. The observability of the results gained from the adoption of such innovations increases over time but is low at the start as their advantages mainly consist of avoiding negative impacts of stresses or limiting soil fertility losses and though yields are expected to improve, they do so only after a lag period. Thus, observability of these innovations in the short term is limited and many of the expected results act to mitigate and develop sustainability and resilience in the long run. Trialability depends on the innovation but is generally neither easy nor hard and is facilitated by the fact that other producers already make use of these innovations.

When it comes to compatibility though, it is shown to vary between clusters of producers. For composting and mulching: some producers believe it goes against their culture and customary way; others see it as a too high increase in workload compared to the current system they use; others simply think the adoption of such innovations will not be effective. Producers who have learnt of the innovations from a workshop appear to be those who perceive the innovations as the less compatible while those producers who have learnt through hearsay appear to be those who perceive them as the most compatible amongst clusters. This can be explained by the fact that producers who hear about such innovations from a fellow producer who himself adopted the practices will more easily see the innovations as compatible with his production context and situation as he can more easily identify to the other producer's situation. Results show that small landowners seem to be more conservative than big landowners but big landowners are more reluctant to adopt innovative intensification practices. Understandably, one can hypothesize that their current system of land use satisfies their needs of production while also maximising leisure; whereas small landowners can be viewed to feel more the pressure on land and thus to be keener to accept the workload as a necessity to further intensify their production, even though it entails a decline in leisure. Interestingly, producers from the previously established first cluster are generally keener to accept the workload than those from the second cluster. In this sense, producers who tend to have pushed non-innovative agricultural intensification to higher levels by reducing fallow lengths and garden sizes tend to perceive a higher compatibility and thus perceive a higher relative advantage from innovative intensification practices.

Results show that the state of diffusion of innovative intensification practices on Sandfly Island is still at an early stage but is on its way. Indeed, the fact that, from the interview sample, 5 people have adopted innovations out of the population of potential adopters of 40 thus a total adoption rate of 12,5% shows that not only producers from the "innovators" group but also from the "early adopters" group have made the decision of innovation adoption. As theory and results point out, these people are much involved in local community life, are much respected and can be expected to have a high influence on the rest of the population of potential adopters. This is reflected in the high-perceived innovation compatibility for producers who have learnt of innovations from hearsay. All producers who have adopted these innovations are from the Leitongo district.

In consequence, results confirm that in the case of Sandfly Island, innovative intensification will diffuse more easily amongst producers from a higher population area who generally have undergone higher non-innovative intensification as well as amongst small landowners who tend to also occur in more densely populated areas, thus producers from the first cluster. These producers can hardly further non-innovatively intensify their agriculture and therefore are more inclined to accept the workload required to adopt new innovative intensification practices. Symmetrically, innovative intensification will diffuse less easily amongst producers from a lower population area and amongst big landowners, i.e. producers from the second and third clusters, as their system of land use can still non-innovatively intensify and provide sufficient production while requiring less work than adopting innovative intensification practices.

The blockage of tradition in the innovations' diffusion is of major importance though it is shown to be reduced when producers start talking about these innovations amongst each other rather than learning of them from an external source. In this sense, the role of early adopters is once more emphasised as crucial for an efficient diffusion. The high number of producers asking for more advice and guidance underlines the important role that early adopters and innovators could play if they were recognized and invited to act as demonstration farmers or referents in terms of agriculture. Nevertheless, as is illustrated in Charles Lui's case, incentives to become such a referent are dampened because of the customary rule that a host should provide food to his visiting guests. This high number also indicates that many interviewed producers who are aware of the presented innovations are also open to consider their adoption though the change to something different than what they were born in makes them dubious they can do it on their own; this gap should close gradually the more producers adopt new farming styles.

No producers who took part in a workshop reported a lack of knowledge and understanding of the practices, which is a positive feedback for extension agents; the crux of the matter appears to rather be in knowledge in practice as many complain about not knowing how to practically implement practices. This contrasts highly with the surprisingly high number of producers who learnt from school and reported a lack of understanding; from conversations with Jon Gomi, principal of Siro Community High School, and with Pita Tikai from KGA, it has been observed that agricultural teachers in high schools are often disregarded as they are considered to lack practical skills. Being taught at SINU (the Solomon Islands National University), their training is criticized as being too theoretical and, some exceptions aside, the course in agriculture all high school students follow is very much neglected. Though it is understandable a high school course might not be sufficient to engage students in changing traditional agriculture, one could hope it would help students identify the pressures on local agriculture and raise awareness efficiently as a further basis to build upon with other sources of extension. Children most often learn the required gardening skills by accompanying their parents in their daily tasks, not through school. Thus the fact that children appear to faithfully replicate their parents' practices ensures that practices are consistently passed from generation to generation amongst families of producers who have made the decision to adopt innovative intensification.

The innovations introduced for strengthening income generation such as vanilla production have a generally high complexity, high observability, very low triability and low compatibility and thus will certainly only present relative advantage for those producers who have the specific goal of improving cash earnings.

5.7 Hidden costs of adoption of non-shifting agriculture

Charles Lui's case demonstrates that the adoption of a new farming style goes beyond the mere adoption of innovations. To adopt a non-shifting agriculture model, Charles also adapted a different lifestyle and with this adoption come some costs that are not taken into account in the section above. These adoption costs affect differently households from different clusters.

For households of the first cluster, to switch to a non-shifting agriculture system, households will probably need to move out of the village as it is highly probable that land they own close to the village is too small, scattered or steeply inclined to prove worthy of long term investment. In this case, the household will most probably have to move to someplace away from dense population areas where they can find appropriate land conditions. If the mentioned piece of land is tribal land, they should consider purchasing it to establish ownership of the settlement. The additional cost of building a new house is high, purchasing land too. Furthermore, there is also a social cost to it as the household moves away from a village close to friends, family and infrastructures such as schools, canteens, medical centres and places of worship. As benefit, additionally to those conferred by the system of land use discussed previously, the household is close to its gardens and does not have to canoe or walk long distances every time it wants to work in the garden or harvest it; they avoid the much physical work of clearing fallows twice a year; additionally, a closer monitoring enables quick reaction to stresses such as pests and weeds and it helps to avoid harvest losses as timing of harvest can be closely followed.

For households of the second cluster, a non-shifting system of land use is compatible with households' general current lifestyles as quality agricultural land is more available around village areas. The social and capital costs of the first and third clusters are avoided, unless private land needs to be purchased to the tribe. The family can decide to focus exclusively on its most fertile, productive land or the closest land to the household or a compromise between the two. Benefits are the same though the time gained from a shorter walk to gardens might be of lesser importance. Households from the third cluster share aspects of the two situations, depending on their contexts.

In consequence, though innovations are shown to diffuse more easily amongst households of the first cluster, these are also the households whose adoption will imply higher costs. These barriers are of less importance for an intermediate-intensified system of improved fallow where producers adopt brush-and-hoe, mulching and/or composting and make use of contouring in sloping areas. Indeed, in this way, producers do not undergo too big a change in system of land use while taking a first step in the direction of sustainability.

5.8 Insights for future extension

This work shows how diverse a community can be, even for such a small place as Sandfly Island. The approach chosen in this work of looking at producers' attitude towards innovative intensification as a function of their farming styles, and thus common environmental constraints to production, could serve for further extension efforts. This can help direct knowledge and awareness of the right practices to the right people. The very high stated need for guidance in the adoption of agricultural innovations stresses out the necessity for local models and referents for agriculture. From the outside, help to implement demonstration farms and the call for lead farmers would highly benefit communities. From the inside, communities should encourage the creation of a tribal or community roles of agriculture referent and encourage the creation of places of agricultural knowledge exchange. These places could be articulated around schools or places of worship. Indeed, what this work also puts to light is the limited circulation of knowledge between those producers who detain knowledge of agricultural innovative intensification practices and are ready to share it and the people who are aware of their need for such practices but lack the knowledge.

5.9 A broader perspective

Other solutions exist to cope with demographic rise and the effects of climate change. The Solomon Islands are living through a period of important rural-urban migration reaching levels of urban growth of 4.7% per year (UN-Habitat, 2012). Sandfly Islanders make frequent trips to Honiara and, according to paramount chief of Gela Peter Mike, an approximate 100 people leave the island every year either to settle in Honiara or for the purpose of intermarriage with other island communities. As stated in the Methodology, Sandfly Island is one of the most densely populated areas of the Solomon Islands. The neighbouring Small and Big Gela for instance, have a significantly lower population density and plenty of available land, though they share a rugged relief. Some producers from the Leitongo district have been observed to regularly cross Sandfly Passage to clear new gardens on the neighbouring island's coastal grounds: immigration to Honiara or surrounding islands might come to increase when Sandfly Island land availability hits a critical level and thus help turn down the build-up of pressure on land.

All agricultural recommendations done for the Sandfly Island community apply to other Solomon Islands communities as they respond to a global change that affects all, though to varying degrees. Increase of population especially and the concomitant pressure on land rarely affects those communities living on the bigger islands of the country. Nevertheless, despite a very low national average population density, it hides many places of high population density with increased pressure on land such as Taro Island in Choiseul, Savo in Central Province, atolls in the province of Malaita, Santa Catalina in Makira and Ulawa, Tikopia, Anuta and the islands of Temotu (AusAID, 2006). Other communities of the Pacific are currently undergoing similar pressures on land. Furthermore, the challenge of climate change affects all, no matter the state of population density.

5.10 A thought on adoption of innovative intensification

Boserup (1965)'s idea that an increasing population growth entails intensification of agriculture fits with the case of Sandfly Island; in fact, the core of her idea stating that population growth is independent of food supply seems to be confirmed as producers' agricultural output is shown to be declining while population is increasing, the phenomenon is more markedly observed in high population areas; contradicting Malthusian theories.

The application of DIT to the case gives us perspective on the reasons why such intensification might take place. It appears that producers from a context with a higher population density are subject to a faster non-innovative intensification and thus develop farming styles with a characteristic extension of cropping period, reduction of fallow length and size of farmable area to answer to an increased environmental constraint of lower land availability in such a way that producers in such a context perceive intensification innovations with a higher degree of compatibility and offering a higher relative advantage, than those producers from a lower population density area. There are reasons to believe consequently, given that producers recognize, or are spread awareness about the problem of population growth, that adoption rates of agricultural intensification innovation will be higher in more densely populated areas.

Critical view of data

When collecting data, several challenges were encountered. The first obvious one is that of language and both the quality of the way questions were asked and how answers were understood and transcribed improved over time as the author's skills in Pidjin and his global understanding of local nuances in vocabulary and custom got better. Secondly a global cultural difference could be felt in the perception of sense of ownership, time, space and planning in general; and the Cartesian approach of the way interview questions were asked in order to obtain numerical, comparable answers was often met with a troubling relativism. Indeed, where the author expected to collect precise data on the number of plots in producers' rotations, fallow and cropping period lengths and size of plots, the most usual answer to his questions was "It depends". In facts, such is producer's reality on Sandfly Island: the size of a plot depends on the size of the previous harvest; the size of the previous harvest depends on the length of the fallow accorded to the cleared plot; fallow length depends on the cropping period of used plots and on available space and number of plots; available space and number of plots depends on the size of previous harvest as one area can be split in one or more plots depending on the speed of vegetation regrowth on other fallow plots, etc. It is a complex mesh of interwoven relative threads. Nevertheless, when interviewees were nudged a bit, most could give a consistent numerical answer of their production system's average. Displayed results are therefore to be approached as indicators of fluctuating measures because… It depends! Thirdly, every interviewee's gardens could not be visited thus garden sizes were estimated by having interviewees spatially represent their gardens' sizes by pointing at varying distanced landmarks surrounding the site of interview. Spatial data thus suffers an important bias. More generally, the sample of interviewees suffers a small bias because of the way communities were approached: local chiefs and elders had to be consulted before interviews could be conducted in the various locations. Many were thus interviewed as they often were good English speakers and perceived by the author as representative voices of communities with a broad perspective.

The variability between soil sampling sites in management history and knowledge about it complicates soil analysis interpretation. The laboratory analysis of soils served as a first experience for the author and, though Erik Karltun supervised it, some errors might have occurred. Most results are consistent though some numbers are surprising: exchangeable acidity should be close to zero for the sandy soil and plant-available P levels are often shown to decrease to zero which is unusual. The latter can be explained by the fact that the method employed asks for a certain time for the reaction generating the blue ammonium molybdate compound to be complete. During the first attempt, the author waited roughly 12 hours overnight between the start of reaction and time of analysis; unfortunately, resulting sample colour had become too homogeneous and intense across samples. The author then repeated the analysis and waited 90 minutes between the start of reaction and time of colorimetric measure; the results were thought to better match reality though have been shown to underestimate plant-available P levels. There is a flaw in the chosen operational definition of CEC as the sum of EAC and EBC that can be seen in the fact that the red soil has the highest CEC of all analysed soils just because it has very high levels of EAC.

Limitations

As mentioned before, the absence of replicates for the soil fertility comparison limits thoroughly the significance of the resulting analysis. To make the study more complete, not only could have replicates been sampled but focus could also have been brought on the impact on soil fertility of other land uses across the island and on the different types of soil. In order to study this, more time would have been needed.

Data on yield levels would have been precious to get an idea of the difference of output per man-hour of the different studied agricultural systems. The author with the given time could not do collection of such data. The local conditions of continuous cropping and harvest with no specific seasonality make the task arduous. Likewise, as much of the harvests are destined to personal consumption and subsistence, few producers collect information on sizes of yields. Many studies have been conducted on this topic but mostly in other geographical zones such as on the African continent and, though the load of work required for the different agricultural systems could be homogeneous across continents, the yields resulting from such practices are bound to differ much from one area to the next. Reviewing literature for levels of output per man-hour in different conditions could still have been relevant.

Picture 4. View of Sandfly Island from the ridge above Sodulu. Picture by M. Michelet

6. Conclusion

Locals recognize five soils on Sandfly Island, distinguished by texture and fertility for cropping. Local knowledge describes accurately the differences in fertility of local soils but does not situate it amongst a global scale of soil fertility. When placed on a global fertility scale, soils are shown to lack P and K and display a low CEC, for this reason, fallow periods are important to build up fertility for agriculture. Nevertheless, the current agricultural system of bush fallow is shown to be the result of non-innovative intensification of the customary forest fallow system under the constraint of declining land availability. Non-innovative intensification has happened under the form of a shortening of fallow lengths, a decrease in cropped area size and an extension of agriculture to marginal land. This type of intensification has been pushed to further extent in more densely populated area, which confirms ideas that agricultural intensification responds to demographic rise in pre-industrial communities. In places of high intensification, agriculture is hitting a critical level where it is hard to intensify any farther in a non-innovative way. On the other hand, locally observed symptoms of climate change point out to a decline in the conditions of production on land. All in all, yields are shown to decline and harvested crops to become smaller. Innovative intensification possibilities to reach sustainability in the face of climate change and population increase are multiple. Nevertheless, the usual introduction of either drought animals manure fertilization, irrigation or chemical fertilizers is not conceivable because of the local context of an isolated community in a developing country. Alternatives include mulching, composting and the use of contouring. These innovations not only benefit producers by providing a means of soil amendment but also help protect soils from the deleterious effects of climate change and secure production resilience and sustainability. These practices are already diffusing through the population of Sandfly Island and some innovators and early adopters have adopted the practices in various ways. Adoption of these innovations would be helpful to all though most beneficial to producers of the denser populated areas. The application of Diffusion of Innovations Theory to collected results shows that producers from such areas are also those who are more prone to perceive a higher relative advantage from the adoption of these practices and thus induce a higher adoption rate. Nevertheless, these producers are also those who would have to pay a higher adoption cost to adopt the more beneficial model of non-shifting agriculture. The intermediate model of improved fallow would offer lower costs of adoption and its adoption might show the way to sustainability.

To conclude, the diffusion of innovative intensification agricultural practices such as mulching, contouring and composting would be beneficial for Sandfly Island producers and for those of any other community of Melanesia under the pressures of climate change or of a rising population. Indeed, means of fertilization are a keystone to enable a further intensification of agriculture and to achieve sustainability; these practices fulfil this need by promoting a closing of nutrient cycles while generating very little costs.

Further study should be made to more accurately understand the expected impacts of such practices on agricultural yields and soil fertility. To further understand the diffusion of innovative intensification practices on Sandfly Island, more research is needed as to follow its evolution.

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Picture 5. Participants of the workshop organized in Siro Community High School. Picture by M. Michelet

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9. Appendices

9.1 Soil fertility indicators explained

The process of exchanging ions between soil particles and the roots is vital to plant growth (Jensen and Husted, 2009), the cation exchange capacity (CEC) of a soil is a measure of those negative charges present per mass of soil, responsible for the binding of crucial positively charged ions (cations) to the soil particles. Clay particles and organic matter develop these negative charges. CEC is therefore a measure of soil fertility for it acts as indicator of texture, mineralogy and SOM. It is measured in cmol of negative charges per kg of soil.

Essential nutrients are the specific elements that are most important to plant growth. Some cations bound to the negative charges sites of the soil are not essential, they are generally referred as acidic cations in opposition to base cations. Na^+, K^+, Mg^{2+} and Ca^{2+} are the base cations and all of them are essential except Na^+.(Singh and Schulze, 2015) Base saturation (BS) exposes the ratio of negative charges occupied by base cations to acidic cations and serves therefore as a soil fertility indicator for soil mineralogy and nutrient concentration. It is given in percentage of negative charge sites occupied by base cations, an ideal BS ranges around 60-80% (Marigowda and Sreekumar, 2019)

Nitrogen is commonly referred as the most limiting factor to crop production as it is found in almost none of the soil minerals' elemental constitution. Plants hereby entirely depend on biological Nitrogen fixation of atmospheric Nitrogen gas by prokaryotes. (Syers, Johnston and Curtin, 2008; Stephen C, 2011) Total Nitrogen found in the soil understandably makes for one of the best indicator for fertility when it comes to nutrients concentration. It is given in percentage of total dry weight of the soil.

Phosphorus is another strongly limiting nutrient for crop production. Plants can absorb P only from the soil solution and, even though P is usually abundantly present in soil minerals, the equilibrium between P in the soil solution and P in the mineral phase is very slow to establish. As plants crucially need high concentrations of P during certain development stages, the soil solution is quick to be depleted and slow to be recharged in P. For this reason, plant-available P is a good indicator of soil fertility when it comes to nutrients concentrations. It is given in mg of P per kg of soil, 0,021 mg/kg is the minimum concentration at which roots can take up P from the soil solution. (Sarmiento *et al.*, 2006; Syers, Johnston and Curtin, 2008)

pH is a measure of a solution's acidity. Measuring the soil pH gives an indication of nutrient availability for many plant essential nutrients' availability change whether the soil is neutral (pH 7), alkaline (pH 7,5 and more) or acidic (pH 6,5 or less) as they occur in different chemical forms at different pH, some of these being directly unavailable to plants or more affected by external factors resulting in an indirect lower plant availability. Acidity is given in pH, logarithmically linked to the inverse of the concentration of protons in the solution, an optimal soil pH lies between values of 6,5 and 7,5.

Soil organic carbon (SOC) serves as direct indicator for soil organic matter (SOM) and therefore, of fertility for reasons explained previously. (Bünemann *et al.*, 2016) SOC is given in percentage of weight of dry soil.

To sum it up: CEC and BS are used as indicators for inherent fertility whereas total N, plant-available P, pH, SOC and BS are used as indicators for dynamic fertility.

9.2 Questionnaire and interview questions

Questionnaire questions:

- What is your name?
- Where do you live?
- Has your village changed over your lifetime?
- How many children do you have?
- Do you have a job?
- Do you have a garden?
- How long do you stay on one garden before you leave it in fallow?
- How long is your average fallow?
- How many garden plots do you have in your rotation?
- Describe the plots in terms of soil type, size and slope.
- Is the food from your garden enough to feed your family?
- Do you buy food at the market?
- What type of food?
- What are your income sources?
- Do you know about climate change?
- If yes, where have you heard of it?
- What are the impacts of climate change on Sandfly Island?

Interview questions:

- Do you know of gardening practices that add fertility to the ground?
- Where did you learn of them?
- Do you use them in your garden?
- Why/Why not?

9.3 Specific interviews questions

Charles Lui

- Have each tribe equal access to land?
- How can one purchase private land?
- How is private land handed over from owner to owner?
- How is tribal land shared?
- What does it imply for Sandfly Island community to be matriarchal?
- Are there social classes amongst islanders?
- What is the legal role of clans and tribes in community life?
- What is the traditional sharing of work tasks in a household between man and wife?
- How did you learn of a different way of producing food?
- What convinced you to adopt it?
- Why do other people not do the same?
- Why keep mulching of all the learnt practices?
- What would you do if you did not have flat land at your disposal?
- Does your faith play a role in the way you approach farming?
- Do you know of climate change?
- What are its effects on Sandfly Island?

Peter Mike

- What is your role as paramount chief of Gela?
- What changes have you observed on Sandfly Island in your lifetime?
- Do many people leave Sandfly Island? Where do they go and why?
- Is there a shortage of land on Sandfly Island?
- What do you think of non-shifting agriculture? Why don’t people adopt it?

Pita Tikai

- What are the blockages encountered by KGA in the extension of sustainable agriculture?
- Why aren’t agriculture teachers listened to?

9.4 Soil profile description

1. Black soil description sheet

GENERAL INFORMATION

Registration and Location
Soil profile number : SISB
Soil Profile Description Status :
Date of description : 190815
Author(s) : Matthieu Michelet
Location : outskirts of Hugu Organic Farm compounds
Elevation : 5m
Map sheet number, grid reference, coordinates : -08,98216 ; 160,08537

Soil Classification
WRB, 2006 : Fluvisol
USDA taxonomy : Tropofluvent
Soil Climate
Mean annual air temp. : 26°C
Mean annual precip. : 3000 mm

Landform and Topography
Topography : Hilly
Landform : Alluvial plain
Land element : Floodplain
Position : Lower part
Slope : Level
Micro-topography : No micro-relief

Land use and Vegetation
Land use : Clear felling
Human influence : Clearing, burning
Vegetation : woodland
Grass cover : 0-15%

Parent Material
Parent material : Alluvial deposits
Effective soil depth : Moderately deep

Surface Characteristics
Rock outcrops : None
Surface coarse fragments : Fine gravel
Erosion : Rill erosion, deposition by water
Surface sealing : None
Other surface characteristics : Ash

Soil-Water Relationships
Drainage Classes : Moderately well drained
Internal drainage : Saturated for short periods in most years
External drainage : Neithere receiving nor shedding water
Flooding : Monthly
Groundwater : Moderately deep

Moisture conditions : Slightly moist

BRIEF GENERAL DESCRIPTION OF THE SOIL

Deep, moderately imperfectly drained, dark grey yellowish loam soil developed on successive layers of fluvic materials with mixed colluvic materials.

SOIL HORIZON DESCRIPTION

$1A_h$ 0-20 cm, abrupt smooth boundaries, granular, dark grey to black organic surface horizon, many thick and fine roots,

$1A_g$ 20-30 cm, abrupt smooth boundaries, grey-brown matrix, angular blocky, abundant coarse yellow, red and white colluvic and fluvic both hard and soft residual rock fragments (NK), few weathered fine gravel of same origin, common fine roots.

1B 27-? Cm, abrupt smooth boundaries, dark grey loam getting darker as it gets deeper, few coarse yellow red and white colluvic and fluvic both hard and soft residual rock fragments (NK), few weathered fine gravel of same origin, pockets of higher abundance of residual rock fragments.

Appendix Figure 1: Black soil profile, picture by Matthieu Michelet

Appendix Table 1: Black soil fertility parameters, result of soil analysis.

	$1A_h$	$1A_g$	1B
Depth of sampling (cm)	15	25	50
pH	6,5	6,9	6,9
P (mg/kg)	7,4	3,5	0,0
TN (% of weight)	0,275	0,054	0,050
SOC (% of weight)	2,9	0,51	0,56
CEC (cmolc/kg)	3,6	3,6	3,8
Exch. Ac (cmolc/kg)	0,79	0,79	0,71
BS (%)	78	78	81
K^+ (cmol/kg)	0,047	0,032	0,035
Ca^{2+} (cmol/kg)	0,11	0,12	0,12
Na^+ (cmol/kg)	0,11	0,11	0,16
Mg^{2+} (cmol/kg)	2,6	2,6	2,8

2. Brown soil description sheet

GENERAL INFORMATION

Registration and Location
Soil profile number: SIHSB
Soil Profile Description Status:
Date of description: 190815
Author(s): Matthieu Michelet

Location: newly brushed garden of Rose, Hugu hillside.
Elevation: 20m
Map sheet number, grid reference,
coordinates: -08,98372 ; 160,08609

Soil Classification
WRB, 2006: Cambisol
USDA taxonomy : Eutropept
Soil Climate

Mean annual air temp.: 26°C
Mean annual precip.: 3000 mm

Landform and Topography
Topography: Hilly
Landform: Hill
Land element: Slope

Position: Lower slope
Slope: Sloping
Micro-topography: Low gilgai

Land use and Vegetation
Land use: Clear felling
Human influence: Clearing, burning

Vegetation: Woodland
Grass cover: 0-15%

Parent Material
Parent material: Metamorphic rock

Effective soil depth: Moderately deep

Surface Characteristics
Rock outcrops: None
Surface coarse fragments: Fine gravel
Erosion: Rill erosion, water deposition

Surface sealing: None
Other surface characteristics: Ash

Soil-Water Relationships
Drainage Classes: Well drained
Internal drainage: Never staurated
External drainage: Moderately rapid

Flooding: None
Groundwater: Not observed
Moisture conditions: Slightly moist

BRIEF GENERAL DESCRIPTION OF THE SOIL

Deep , freely drained, dark loamy topsoil over yellowish brown lower horizons.

SOIL HORIZON DESCRIPTION

A_h 0-19 cm, gradual broken boundaries, dark brown, fine angular blocky structure, few angular fine gravel, many coarse and fine roots,

A 19-32 cm, clear broken boundaries, brownish grey, angular blocky, few angular fine gravels, common fine roots, very few coarse roots.

B_g 32-43 cm, gradual broken boundaries, dark greyish brown, angular blocky, few coarse yellow red and white colors both hard and soft residual rock fragments (NK), and few angular fine gravel.

Appendix Figure 2: Brown soil profile, picture by Matthieu Michelet

Appendix Table 2: Brown soil fertility parameters, result of soil analysis.

Horizon	A_h	A	B_g
Depth of sampling (cm)	2	25	50
pH	7,0	6,9	6,9
P (mg/kg)	20,1	3,5	0,0
TN (% of weight)	0,31	0,054	0,050
SOC (% of weight)	4,1	0,51	0,56
CEC (cmolc/kg)	3,5	3,6	3,8
Exch. Ac (cmolc/kg)	0,75	0,79	0,71
BS (%)	79	78	81
K^+ (cmol/kg)	0,061	0,032	0,035
Ca^{2+} (cmol/kg)	0,13	0,11	0,12
Na^+ (cmol/kg)	0,12	0,11	0,16
Mg^{2+} (cmol/kg)	2,5	2,6	2,8

3. Yellow soil description sheet

GENERAL INFORMATION

Registration and Location
Soil profile number: SIYS
Soil Profile Description Status:
Date of description: 190817
Author(s): Matthieu Michelet

Location: Eastern hillside 20m out of the bush from the path leading up the hills from Hugu.
Elevation: 120m
Map sheet number, grid reference, coordinates: -08,97928 ; 160,08282

Soil Classification
WRB, 2006: Cambisol
USDA taxonomy : Dystropept
Soil Climate

Mean annual air temp.: 26°C
Mean annual precip.: 3000 mm

Landform and Topography
Topography: Hilly
Landform: Hill
Land element: Ridge

Position: Upper slope
Slope: Moderately steep
Micro-topography: No micro-relief

Land use and Vegetation
Land use: Not used and not managed
Human influence: Burning

Vegetation: Tall grassland
Grass cover: >80%

Parent Material
Parent material: Metamorphic rock

Effective soil depth: Moderately deep

Surface Characteristics
Rock outcrops: Few
Surface coarse fragments: Common coarse gravel

Erosion: Severe Rill erosion, water and wind erosion
Surface sealing: Medium

Soil-Water Relationships
Drainage Classes: Well drained
Internal drainage: Never saturated
External drainage: Rapid

Flooding: None
Groundwater: Not observed
Moisture conditions: Slightly moist

BRIEF GENERAL DESCRIPTION OF THE SOIL

Moderately deep, highly weathered yellow clays and loams, high surface wind and water erosion, with charcoal inclusions in subsurface horizons.

SOIL HORIZON DESCRIPTION

A 0-7 cm, abrupt irregular boundaries, black, fine granular structure, few angular fine gravel, many fine roots.

AB 7-55 cm, clear irregular boundaries, yellowish brown, angular blocky, dark inclusions of organic matter, common coarse subrounded yellow white and red both hard and soft residual rock fragments (NK), few angular fine gravels, common fine roots

1C 55- 75cm, clear smooth boundaries, bluish grey, plate-like.

2C 75-. cm, unobserved boundaries, yellowish brown to light brown, block-like.

Appendix Figure 3: Yellow soil profile, picture by Matthieu Michelet

Appendix Table 3: yellow soil fertility parameters, result of soil analysis.

Horizon	A	AB	1C	2C
Depth of sampling (cm)	2	30	70	90
pH	6,1	6,9	6,7	6,7
P (mg/kg)	0,53	0,12	0,0	0,0
TN (% of weight)	0,23	0,089	0,037	0,004
SOC (% of weight)	3,4	1,0	0,43	0,10
CEC (cmolc/kg)	4,1	4,0	4,9	5,2
Exch. Ac (cmolc/kg)	1,0	0,83	1,4	1,2
BS (%)	75	79	71	77
K^+ (cmol/kg)	0,055	0,033	0,043	0,034
Ca^{2+} (cmol/kg)	0,098	0,11	0,12	0,18
Na^+ (cmol/kg)	0,10	0,11	0,12	0,12
Mg^{2+} (cmol/kg)	2,8	2,9	3,2	3,6

4. Red soil description sheet

GENERAL INFORMATION

Registration and Location
Soil profile number: SIR
Soil Profile Description Status:
Date of description: 190814
Author(s): Matthieu Michelet

Location: Western hillside 40m uphill from the crossing of the second stream on the path from Hugu to Pandudura
Elevation: 120m
Map sheet number, grid reference, coordinates: -08,97906; 160,07990

Soil Classification
WRB, 2006: Ferralsol
USDA taxonomy : Acrorthox
Soil Climate

Mean annual air temp.: 26°C
Mean annual precip.: 3000 mm

Landform and Topography
Topography: Hilly
Landform: Hill
Land element: Ridge
Position: Upper slope

Slope: Moderately steep
Micro-topography: small erosion canyons, terracettes

Land use and Vegetation
Land use: Not used and not managed
Human influence: Burning

Vegetation: Grassland
Grass cover: >80%

Parent Material
Parent material: Metamorphic rocks

Effective soil depth: Shallow

Surface Characteristics
Rock outcrops: Few
Surface coarse fragments: Few coarse gravel

Erosion: Severe gully erosion, water and wind erosion, landslides
Surface sealing: Medium, hard

Soil-Water Relationships
Drainage Classes: Well drained
Internal drainage: Saturated for short periods in most years
External drainage: Rapid run-off

Flooding: None
Groundwater: Not observed
Moisture conditions: Slightly moist

BRIEF GENERAL DESCRIPTION OF THE SOIL

Shallow, highly weathered red clay, acidic soil with almost no OM accumulation, severe water erosion causing deep gullies and landslides.

SOIL HORIZON DESCRIPTION

A 0-15 cm, clear irregular boundaries, dark brownish red, granular structure, many fine roots.

B 15-? cm, unobserved boundaries, yellowish red, massive structure breaking down in angular blocky structure, common coarse white mottling with sharp boundaries particularly marked around roots, very few fine roots disappearing under 60 cm.

Appendix Figure 4: Red soil profile, picture by Matthieu Michelet

Appendix Table 4: Red soil fertility parameters, result of soil analysis.

Horizon	A	B
Depth of sampling (cm)	4	60
pH	5,5	5,3
P (mg/kg)	0,0	0,0
TN (% of weight)	0,10	0,045
SOC (% of weight)	1,8	0,54
CEC (cmolc/kg)	6,1	7,2
Exch. Ac (cmolc/kg)	3,5	4,5
BS (%)	42	38
K^+ (cmol/kg)	0,035	0,055
Ca^{2+} (cmol/kg)	0,015	0,010
Na^+ (cmol/kg)	0,10	0,10
Mg^{2+} (cmol/kg)	2,4	2,6

5. Sandy soil description sheet

GENERAL INFORMATION

Registration and Location
Soil profile number: SISS
Soil Profile Description Status:
Date of description: 190818
Author(s): Matthieu Michelet

Location : Siro community high school grounds, border of the grass field close to shore.
Elevation: 2m
Map sheet number, grid reference, coordinates: -08,98435; 160,07303

Soil Classification
WRB, 2006: Arenosol
USDA taxonomy : Troporthent
Soil Climate

Mean annual air temp.: 26°C
Mean annual precip.: 3000 mm

Landform and Topography
Topography: Hilly
Landform: Coastal plain
Land element: Beachridge

Position: Lower part
Slope: Flat
Micro-topography: Level

Land use and Vegetation
Land use: Lawn
Human influence: Clearing

Vegetation: Grassland
Grass cover: >80%

Parent Material
Parent material: Marine deposits

Effective soil depth: Shallow

Surface Characteristics
Rock outcrops: Few
Surface coarse fragments: Many coarse and medium gravel

Erosion: No evidence of erosion
Surface sealing: None

Soil-Water Relationships
Drainage Classe: Somewhat excessively drained
Internal drainage: Never saturated
External drainage: Neither receiving nor shedding water

Flooding: None
Groundwater: Not observed
Moisture conditions: Dry

BRIEF GENERAL DESCRIPTION OF THE SOIL

Shallow, excessively drained, coarse corallic sandy soil with large coral fragments.

SOIL HORIZON DESCRIPTION

A 0-45 cm, abrupt wavy boundaries, black, coarse sand, granular structure, abundant fine medium and coarse subrounded coral debris, many fine roots.

B 45-? cm, unobserved boundaries, white unconsolidated fine medium and coarse coral debris, few fine roots and very few coarse roots.

Appendix Figure 5: Sandy soil profile, picture by Matthieu Michelet

Appendix Table 5: Sandy soil fertility parameters, result of soil analysis.

Horizon	A	B
Depth of sampling (cm)	15	50
pH	7,91	8,53
P (mg/kg)	2,97	0,48
TN (% of weight)	0,25	0,024
SOC (% of weight)	3,16	0,86
CEC (cmolc/kg)	2,25	1,86
Exch. Ac (cmolc/kg)	0,57	0,10
BS (%)	70,5	75,3
K^+ (cmol/kg)	0,056	0,041
Ca^{2+} (cmol/kg)	0,14	0,13
Na^+ (cmol/kg)	0,18	0,14
Mg^{2+} (cmol/kg)	1,22	1,1