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Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu

Edited by Steve Harrison and Md Saiful Karim

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ACIAR Monograph MN191

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Foreword

Fiji and Vanuatu, along with other Pacific island countries, have a long history of mixed species agroforestry (MSA). Integrating a variety of tree species into village and home gardens, and mixed livestock and crop systems, provides a sustainable source of timber, food and many other traditional products. However, the extent of agroforestry declined during the colonial era and the subsequent urbanisation of Pacific island populations.

Various agroforestry benefits have been recognised—notable examples include increased national self-sufficiency in timber and fuelwood, higher nutritional status of the population, watershed protection, improved utilisation of degraded and marginalised cropping land, strengthening of agricultural infrastructure, genetic conservation, carbon capture, and improved wildlife habitat and landscape amenity.

This collection of 15 working papers, prepared by an ACIAR-funded research team led by Dr Md Saiful Karim and with advice from Professor Steve Harrison, provides valuable insights into the current status of MSA in Fiji and Vanuatu. It identifies technical opportunities and constraints, and financial, policy and legal aspects. Agroforestry is an appropriate land use for underutilised moderately sloping land between cropping and forestry areas. A wide variety of traditional timber, fruit and nut tree species and food and other crops are suitable for growing in these areas. Much of the land is degraded from clearing, past cropping and wildfire. Challenges arise with respect to financing and managing relatively complex farming systems, post-harvest processing and storage, and transport and marketing of produce.

The papers in this monograph explore how to improve financial and broader economic analysis of agroforestry systems. They also examine legal, capital, labour, management and policy measures that could facilitate agroforestry in Fiji and Vanuatu. Financial analyses of various individual tree and crop species, and of example mixed-species models, are provided for both Fiji and Vanuatu. The information presented in this monograph offers valuable insights into the potential for further agroforestry development in Fiji and Vanuatu, and indeed other Pacific island countries.

Professor Andrew Campbell
Chief Executive Officer, ACIAR

Contents

Preface

A number of working papers have been prepared under ACIAR project ADP/2014/013, 'Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu'. These are based on literature searches, fieldwork in Fiji and Vanuatu, discussions with project participants and other key informants in Fiji, Vanuatu and Australia, and discussions with researchers participating in other ACIAR projects. The papers have been designed to share information among research teams in project ADP/2014/013 as well as project ADP/2014/012, 'Improving livelihoods and economic progress through rehabilitation of degraded catchments in Fiji and Vanuatu', in order to provide a common understanding of research issues, and as far as practicable, a consistent research methodology. In addition, the working papers report on major findings of project ADP/2014/013 and provide background to information in the final report of project ADP/2014/012.

These working papers have been compiled into a monograph to accompany the final report of project ADP/2014/013 and provide greater detail. Along with the final report and workshop papers, the monograph provides a record of research conducted under project ADP/2014/013 and makes this available to a wider audience interested in agroforestry systems in Fiji and Vanuatu. The working papers also provide a useful basis for further research into agroforestry systems (or ecological intensification) in the two countries.

Among the working papers (WPs) are:

- a macroeconomic overview of agroforestry benefits in Pacific islands (WP1)
- a survey of approaches which have been adopted for modelling the performance of agroforestry systems (WP2)
- the steps required for modelling the financial performance of novel tree species (WP3) and for carrying out a broader modelling approach to include environmental and social benefits of forestry and agroforestry in Fiji and Vanuatu (WP4)
- assessments of the constraints to, and opportunities for, establishing agroforestry in the Western Division of Fiji (WP5 and WP6)
- a survey of the various lists of tree species which have been identified as having priority for growing in Fiji and Vanuatu and the criteria used for their selection (WP7)
- details of financial models of selected individual tree and crop species and mixed-species agroforestry systems, and estimates of financial performance of both groups (WP8 and 9)
- an assessment of the most suitable financing and other measures to promote agroforestry in the two countries (WP10)
- findings from a smallholder survey on the potential for agroforestry adoption in Vanuatu (WP11)
- critical examination of relevant laws and polices relating to agroforestry in Fiji and Vanuatu (WP12 and 13)
- two case studies on existing agroforestry practices in Fiji and Vanuatu (WP14 and 15).

Working papers 2 to 4 have a focus on methodology for financial and economic (cost–benefit) analysis, while the other papers address issues related to the promotion of agroforestry in Fiji and Vanuatu.

It is clear from the working papers that the extent of agroforestry practice in Fiji and Vanuatu has declined in recent decades, including during the colonial era, and that a number of constraints impede further adoption. At the same time, there is a substantial area of underutilised land available—notably at the interface between agricultural cropping and plantation forestry—and major benefits could be achieved from agroforestry expansion if suitable support measures are adopted.

Steve Harrison and Md Saiful Karim

Contributors

Aising, Lazarus
Department of Industry, Ministry of Trade, Industry and Commerce, Tourism and Ni-Vanuatu Business, Vanuatu.

Alauddin, Mohammad
School of Economics, The University of Queensland, Brisbane, Australia.

Bulai, Sairusi
Land Resources Division, Pacific Community (SPC), Suva, Fiji.

Button-Sloan, Alexander
Faculty of Law, Queensland University of Technology (QUT), Brisbane, Australia.

Harrison, Robert
Queensland University of Technology (QUT) and Department of Environment and Heritage Protection, Queensland Government, Brisbane, Australia.

Harrison, Stephen
Queensland University of Technology (QUT), The University of Queensland, and Sunshine Coast University, Australia.

Kabir, Md Jahangir
School of Agriculture and Food Sciences, The University of Queensland, Brisbane, Australia.

Karim, Md Saiful
Faculty of Law, Queensland University of Technology (QUT), Brisbane, Australia.

Kete, Tevita
Land Resources Division, Pacific Community (SPC), Suva, Fiji.

Lagataki, Samuela
Ministry of Fisheries and Forests, Republic of Fiji.

Sullivan, Caroline
Southern Cross University, Lismore, New South Wales, Australia.

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Steve Harrison and Md Saiful Karim

1. The contribution of agroforestry to economic development in Fiji and Vanuatu

Steve Harrison, Saiful Karim, Mohammed Alauddin and Robert Harrison

Abstract

Multi-species agroforestry has for centuries been a widely practised land use in the Pacific islands, including in Fiji and Vanuatu. Various forms of agroforestry are practised, the most widely recognised being mixed-species plantings involving timber, fruit or nut trees intercropped with root crops and other food crops; and silvopastoral systems, such as 'cattle under coconuts'. During and after colonial times, there was a major decline in agroforestry practice. Home and village gardens now have a reduced role as a source of food for households in Fiji and Vanuatu. Current trends of urbanisation, cash cropping and heavy reliance on food imports, together with reduced prices for previously major export crops, have made the need to encourage multi-species plantings particularly apparent. A comprehensive literature review reveals that an impressive range of benefits can be attributed to multi-species agroforestry, including: agricultural diversification; genetic conservation; carbon capture; catchment protection and rehabilitation; strengthening of agricultural infrastructure; increased self-sufficiency in timber and fuelwood; reduced need for food imports; poverty reduction; improvement in the nutritional status of people and associated health benefits; improved utilisation of degraded and marginal cropping land; improved wildlife habitat; and landscape amenity. While agroforestry is a more complex type of land use than monoculture timber plantations, it also offers greater benefits. However, agroforestry is not generally the responsibility of any individual government department, and new forms of governance may be needed to provide a more supportive framework for renewed adoption.

INTRODUCTION

Various forms of agroforestry have been identified in the Pacific islands, including plantation–crop combinations, multipurpose trees, homegardens, alley cropping or hedgerow intercropping, taungya, sequential cropping systems, dispersed trees with understory intercropping, silvopasture, shelterbelts and windbreaks, live fences and border plantings, and improved fallow and land rehabilitation (e.g. Elevitch and Wilkinson 2000; Alavalapati and Mercer 2004; Kumar and Nair 2006). In this paper, the focus is on the first of these forms, which has also been referred to as multi-species agroforestry or MSA (Thaman et al. 2000).

Agroforestry systems are recognised as providing a wide range of benefits in terms of sustainable development at a national level, as well as private benefits to adopters and positive externalities at a local level. Relative to monoculture forestry, the evaluation of these benefits in economic, social or ecological terms is typically difficult due to the complexity of MSA systems. While agroforestry systems have a very long history in the Pacific islands, European colonisation and subsequent independence have led to major changes in land-use patterns. Recent changes in farming systems (e.g. increased cash cropping) and in demography (particularly urbanisation) have led to a movement away from agroforestry. However, since about the mid-1970s there has been increasing recognition of the benefits of agroforestry systems and strong interest in their restoration.

This working paper reviews the evolution of agroforestry systems in Pacific island countries, particularly in Fiji and Vanuatu. The benefits attributed to agroforestry from a national development perspective and at local levels are then examined. Given that single-species plantation forestry and agroforestry share some of the same benefits, an attempt is made to identify differences in the positive contributions of these two types of land use. Some comments are made in relation to the evaluation of agroforestry benefits and further research needs.

EVOLUTION OF AGROFORESTRY IN THE PACIFIC

Agroforestry is a widely practised land use in Fiji and Vanuatu. Various reports have examined the nature of agroforestry systems in these two countries, and the way in which tree–crop systems have evolved in response to changing situations over time. Thaman et al. (2000, pp. 27–30) noted that "thousands of years of observations, study, and experimentation by Pacific island peoples produced a diversity of highly sophisticated multi-species agroforestry systems". These authors described various phases in the evolution of traditional agroforestry systems in the Pacific islands. A highly simplified summary of the phases follows.

Agriculturalisation of the forest. During the first human settlement 1,000 or more years ago, trees were selectively cleared and various plant and animal species introduced. Use of fire led to some deforestation and the development of grasslands. Movement of people between islands, and settlement of new islands, led to introduction of new trees, plants and animals, and 'agroforestry enrichment'.

Colonial agro-deforestation. During the 19th and 20th centuries, colonial governments promoted monocultural export cropping and livestock grazing. Coconuts, cocoa, sugarcane, coffee, bananas, citrus, oil palm, rubber and various vegetable species were grown. Forest clearing accelerated.

Post-World War II agroforestry decline. With greater contact with the outside world, the growing of cash crops and unsustainable logging intensified. Traditional agroforestry practices were discouraged and rates of nutritional disorders increased.

21st century agroforestry re-enrichment. In the late 20th century and into first decades of the 21st century, there has been active promotion of MSA.

Elevitch and Wilkinson (2000, p. 3) observed that "the continued appropriate and well-managed use of trees in agricultural systems can serve as an effective component of sustainable economic development and environmental protection in the region."

THE EVOLUTION OF AGROFORESTRY SYSTEMS IN FIJI AND VANUATU

The various changes in land use mentioned above have been exhibited in Fiji and Vanuatu. Agriculture, and especially agroforestry, is an important land use in both countries, particularly at the household and village level. Coconuts have in the past been a highly important earner of export revenue in both countries. Exports of copra (often from intercropped plantations) and then sugar (as a monoculture crop) became the main foreign exchange earners of Fiji, though these are now secondary to tourism. The profitability of coconut production has declined with falling demand for coconut oil (in part due to health concerns about a high saturated fat content and global expansion in production of other oil crops) and with the ageing and decreased yield of coconut plantations and limited replanting.

Labouisse (as cited by Lamanda 2006) observed a decade ago that about 80% of the population of Vanuatu was involved in agriculture and that about 60% of the cultivated area in Vanuatu was occupied by coconut plantations. Copra production is still highly important in some Vanuatu islands. Lamanda (2006, p. 106) noted the development of large coconut estates by Europeans, especially in the northern islands of Vanuatu, and the later evolution into complex farming systems in which coconut was associated with numerous other species and cattle grazing. Feintrenie et al. (2010) noted the importance of coconut-based agroforestry systems on Malo Island in Vanuatu, where coconut and cocoa estate plantations were introduced at the beginning of the 19th century by European settlers. The estate plantations returned to village ownership after independence in 1980, when mixed-tree systems and cocoa were introduced into the coconut plantations, with vanilla and spices added about the turn of the century.

There has been evidence in recent years of a decline in agroforestry in Pacific island countries, including Fiji and Vanuatu. Clarke and Thaman (nd) reported that "although deforestation, seen as the loss of forest as such, has received much more attention, 'agrodeforestation' is probably of tantamount importance culturally and ecologically. Fewer trees are planted, and the great variety of useful tree species in gardens, villages, and towns is suffering depletion. The situation is particularly serious on smaller islands with little or no remaining native forest, where agricultural areas and home gardens serve as the few reserves where endangered plant varieties or *cultivars* can be protected".

Pattanayak and Depro (2000, p. 165) commented that given the potential benefits of agroforestry "we might expect that agroforestry would be widely embraced by farmers… Despite some impressive technological and scientific advances over the years, however, adoption rates have been low and dis-adoption is not unusual. …this is partly because the claim that agroforestry generates environmental services is largely untested…". Similarly, Nair (2004, p. 355) noted the "recent trend towards commercialisation and consequent conversion of homegardens to produce market-oriented crops…"

CoA[1] (2011) drew attention to the widespread trend towards cash cropping in place of agroforestry in Pacific island countries over recent decades, which has led to shortening of the fallow period with consequent soil fertility loss and weed and pest problems. It was further noted that this is most evident in parts of Melanesia where farmers are changing from shifting cultivation, which had maintained soil fertility and controlled erosion, to annual cropping of the same land, increasing soil erosion and reducing crop yields.[2]

URBANISATION, FOOD IMPORTS AND CHANGES IN DIET IN PACIFIC ISLAND COUNTRIES

As noted by CoA (2011), "the status of food security in the Pacific is the product of a complex equation. In the past, the main variables were natural disasters and population pressure, to which can now be added food imports and rising prices, health risks, political instability, land tenure issues, urbanisation and governance problems". CoA (2011) further noted that rapid urbanisation has been taking place in the Pacific islands with a lack of interest in agriculture, especially on the part of youth. The Pacific islands have high levels of food imports. Further, "the rapid rise in global staple prices, beginning with the 2007–2008 global price crisis, when prices more than doubled, and again in 2010–2011, when they increased even further, mean that households in the Pacific relying on imported foods are facing escalating costs" (CoA 2011). Fiji has price controls on some food and other imported goods, which has been criticised as having a negative impact on local production (e.g. by Narsey 2012). IMF (2013) recommended that "price controls should be scaled back significantly".

CoA (2011) observed that the introduction and promotion of imported foods has led to changes in people's tastes and diets, and all Pacific island countries today depend to some extent on imported foods. Increased consumption of imported foods, especially highly processed packaged foods of low nutrient status, together with excessive dietary calorie intake and more sedentary lifestyles, has been linked to the growing problem of non-communicable diseases across the region (for example, increased hypertension and cardiovascular disease, type 2 diabetes, obesity and micronutrient deficiencies). These problems are probably less severe in Fiji and Vanuatu than in some other Pacific island countries, due to their relatively high food production, although CoA (2011) commented that iodine deficiency and endemic goitre

1 A report was prepared in 2011 by the Secretariat of the Pacific Community (SPC) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the Commonwealth of Australia (CoA) dealing with food security and climate change in 15 Pacific island economies in terms of the four traditional food security issues of adequacy, availability, stability and utilisation.

2 Beer (1988), in a project funded by the German development agency GTZ (now GIZ), observed that there are many shifting cultivation zones in Fiji, but noted that it is difficult "to differentiate between the root crop area … and the shifting cultivation area in the wet zone of Viti Levu, since the main difference is only one of intensity of land use (i.e. length of fallow period)".

are prevalent in the Pacific islands, and especially in Fiji, Papua New Guinea and Vanuatu.

SOME PAST OBSERVATIONS OF THE BENEFITS OF AGROFORESTRY IN FIJI AND VANUATU

Some of the benefits of agroforestry are similar to those widely reported for single-species forestry plantations, but others derive from the combination of species and the wider range of products obtained from agroforestry plantings. Various authors have presented lists of benefits, from a development perspective, which may be derived from increased planting of multi-species agroforestry systems. Some examples, mainly with a Pacific islands focus, are presented below.

Thaman and Clarke (1993) identified national development objectives and agriculture and forestry sector objectives as stated in national development plans of various Pacific island countries. They concluded that promotion of polycultural agroforestry systems would directly or indirectly further the agriculture and forestry objectives of:

1. agricultural diversification
2. promotion of appropriate agricultural technologies and farming systems, both modern and traditional
3. strengthening of agricultural infrastructure, including extension, credit, transport, storage, processing, and marketing
4. improvement in the nutritional status of the people
5. increased self-sufficiency in timber and fuelwood
6. promotion of social forestry or village-level agroforestry (Thaman and Clarke 1993, p. 31).

These authors noted various benefits from pursuing their list of objectives, including encouraging import substitution and improving the balance of payments as well as limiting "ever-increasing foreign exchange problems", increasing returns from underutilised natural and cultural resources, increasing long-term productivity, more equitable and balanced development, improved use of scarce capital and aid, human benefits (especially for the poor and for unskilled workers, including greater availability of coconuts, fruit, vegetables, medicines and firewood), tourism development (as a backstop subsistence for tourism workers and through beautification and stabilisation of beaches), protection of cultural values (e.g. having appropriate food for feasts), improving nutrition, landscape protection and reducing logging pressure on native forests.

Elevitch and Wilkinson (2000) observed in relation to the Pacific islands that well-managed use of trees in agricultural systems can serve as an effective component of sustainable economic development and environmental protection in the region. These authors commented on the deficiencies of monoculture forestry and developed a detailed classification of benefits of agroforestry in the Pacific islands under the five groupings of efficiency of resource use, favourable environment for sustained production, profitability, environmental improvement and cultural compatibility.

Pandey (2002, p. 367) argued that, in addition to carbon sequestration, agroforestry can provide benefits such as "to attain food security and secure land tenure in developing countries, increasing farm income, restoring and maintaining above-ground and below-ground biodiversity, corridors between protected forests, as CH_4 sinks, maintaining watershed hydrology, and soil conservation. Agroforestry also mitigates the demand for wood and reduces pressure on natural forests."

Garrity (2004, p. 5) argued that advances in agroforestry can contribute significantly to the achievement of virtually all of the Millennium Development Goals (MDGs) which "are at the heart of the global development agenda", and the Water, Energy, Health, Agriculture and Biodiversity (WEHAB) initiative. Garrity noted that the World Agroforestry Centre (ICRAF) has identified various challenges that agroforestry can materially address: helping to overcome hunger and poverty, improving health and nutrition, conserving biodiversity, protecting watershed services, adaptation to climate change and building human and institutional capacity. Specifically, the following benefits were listed:

1. Help eradicate hunger through basic, pro-poor food production systems in disadvantaged areas based on agroforestry methods of soil fertility and land regeneration;

2. Lift more rural poor from poverty through market-driven, locally led tree cultivation systems that generate income and build assets;
3. Advance the health and nutrition of the rural poor through agroforestry systems;
4. Conserve biodiversity through integrated conservation-development solutions based on agroforestry technologies, innovative institutions and better policies;
5. Protect watershed services through agroforestry-based solutions that enable the poor to be rewarded for their provision of these services;
6. Assist the rural poor to adapt better to climate change, and to benefit from emerging carbon markets, through tree cultivation; and
7. Build human and institutional capacity in agroforestry research and development.

Thaman et al. (2006, p.25) noted the agro-deforestation taking place in the Pacific islands and commented that "a critical analysis of the nature and future prospects of the urban and homegarden agroforestry systems in these rapidly urbanizing islands suggests that intensification and enrichment of these systems could serve as an important foundation for sustainable development. In addition to addressing the nutrition-related health problems, food security, poverty alleviation, and trade deficits, these systems also help protect and enrich the cultural traditions of Pacific peoples who are increasingly out-migrating from rural areas and embracing urban living."

Garrity (2011) stressed the potential role of agroforestry in forest protection and improvement of degraded land, stating "deforestation isn't an automatic consequence of high food prices... Instead of cutting down virgin forest, farmers can look to expand farming to degraded land. Over the longer term, better investment in agricultural research … can lead to better yields and higher efficiency, reducing the need for more land. …agroforestry can actually combine trees and farming, to the benefit of both. In Africa a growing number of farmers are actually intercropping trees with their farmland, which can cheaply boost nutrients in their soil—certain species of trees actually fix nitrogen, reducing the need for fertilizer—and provide a ready supply of firewood."

Wikipedia (2014) says in relation to payments for ecological services that "there is a 'big three' among … 24 services which are currently receiving the most money and interest worldwide. These are climate change mitigation, watershed services and biodiversity conservation". Clearly, agroforestry has the potential to contribute to each of these three services.

Experiences in other regions reinforce the views reported in Pacific island countries. For example, Nair et al. (2009) drew attention to the potential role of agroforestry for reducing the vulnerability of farming systems to climate variability and climate change impacts, including in semi-arid areas in India. Murthy et al. (2013) identified a range of benefits of agroforestry in India, including:

- Increased soil fertility from leaf litter and reduced run-off and soil erosion;
- Improved income stream from multiple harvests at different times of the year;
- Carbon sequestration of multiple plant species and soil, particularly in degraded soils in humid and temperate regions;
- Buffering against various biophysical and financial risks, reduced seasonal labour peaks, earning of income throughout the year; and
- Higher yields of crops and fodder.

A SYNTHESIS OF AGROFORESTRY BENEFITS

There is considerable similarity in the lists presented by the above sources. Drawing on these, and taking an economic perspective, 11 categories of agroforestry benefits have been identified and are elaborated below. Some of these are widely reported benefits of forestry in general, while others arise from the particular features of MSA.

Agricultural diversification and genetic conservation. Relative to both cropping and forestry, MSA contributes to biodiversity (genetic, species, ecosystem and landscape diversity), for which various benefits are traditionally attributed. Elevitch and Wilkinson (2000) referred to diversity benefits in terms of habitat diversity, species diversity and diversified products. Growing Pacific island tree species—many of which are well suited to use in agroforestry systems and most of which have not been widely grown commercially—can potentially make a major contribution to biodiversity conservation. Agroforestry systems provide an ideal situation for the growing of Pacific island tree and other plant species of high conservation priority. Example priority species listed by Kanawi (2000) are *Santalum* species (sandalwoods), *Terminalia* species (including *T. catappa* or tropical almond) and *Flueggea flexuosa* (namamau or poumuli).

Carbon capture. While the potential exists for certified emission reductions (CERs or carbon credits) to be obtained from agroforestry, the wide variety of agroforestry types and typical small areas of individual growers create various problems in estimation of sequestration amount, additivity and permanence, and transaction costs. Fiji has identified a number of potential Clean Development Mechanism (CDM) projects, and some have already been implemented, including a biomass-fired electricity generation project in Lautoka (Ministry of Foreign Affairs and International Cooperation, c2011). Vanuatu has also identified a number of potential CDM projects, some of which were approaching implementation stage at the time of reporting by the Ministry of Infrastructure and Public Utilities (2012), but none appeared to involve forestry or agroforestry.

Catchment protection and rehabilitation. Suggested benefits include: reduction in soil erosion and soil loss; reduced sedimentation of waterways; improved water quality; reduced downstream flooding (and associated reduced crop and infrastructure damage, and tourism disturbance); reduced damage to the marine environment (mangrove forests and fish breeding areas); improved landscape amenity; and less wildfire with damage to property and tree plantings.

Strengthening of agricultural infrastructure. Expansion of agroforestry has the potential to bring about improvements in extension services, credit availability, transport services, storage and processing facilities, and marketing.

Increased self-sufficiency in timber and fuelwood. Expansion in both monoculture forestry and agroforestry can be expected to lead to increased availability of timber products, including sawn timber, poles and fuelwood, and harvest residue, hence reducing the logging pressure on native forests.

Reduced need for food imports. Given the high level of food imports to Fiji and Vanuatu, and large increases in the cost of imported food as noted by CoA (2011), expansion of agroforestry and improved supply chains and markets for fruit (e.g. mango, citrus), vegetables (including breadfruit and avocado) and nuts (e.g. canarium, barringtonia and macadamia) have the potential to reduce the demand for food imports. For example, breadfruit can to some extent substitute for imported rice. An associated benefit may be reduction in the inflation rates in Fiji and Vanuatu.[3]

Improvement in the nutritional status of people and associated health benefits. As noted by CoA (2011), traditional Pacific diets are based on starchy root crops supplemented by coconuts, fish and sometimes livestock products. Replacement of these foods by white rice and refined flour, along with processed, usually tinned, meats and fish, has had adverse health impacts. Reversing this trend, through increasing availability of locally produced food, will improve nutrition and health status for Pacific people.

Poverty reduction. Agroforestry can lead to increased income of rural people, with associated ability to afford services such as health care and schooling for children.

Improved utilisation of degraded and marginal cropping land. As noted by Nair et al. (2009) and Garrity (2011), agroforestry can be practised on relatively difficult and degraded sites. In Fiji, a sandalwood and vesi system has been suggested; both species have very high value timber and can be grown on relatively dry sites.

Improved wildlife habitat. Dense agroforestry plantings can improve the habitat (e.g. by providing shelter and a food source) of native wildlife and bees.

Landscape amenity. Urban plantings of attractive tree species, and restoration of vegetation in the

3 Based on information produced by the Reserve Bank of Fiji, Trading Economics (2016) reported that "inflation in Fiji averaged 3.87 percent from 2003 until 2016, reaching an all time high of 10.50 percent in April of 2010 and a record low of –0.30 percent in April of 2009".

landscape (or 'greening the barren hills'), will add to the quality of life of residents and also assist in promoting tourism. Various Pacific island tree species are well suited as town and roadside shade trees and ornamentals.

RELATIVE BENEFITS OF AGROFORESTRY VERSUS FORESTRY

At least some of the benefits of agroforestry discussed above would also be generated by expanded plantings of single-species forestry. Therefore pertinent questions are: what benefits does agroforestry have over forestry; and would individual landholders and the region or country be better off growing multi-species rather than single-species plantations? Most of the favoured Pacific island timber, fruit and nut species could be grown in single-species plantations. Monoculture plantations might produce greater quantities of major products (e.g. timber or fruit or nuts) and be simpler to establish and manage. If well-known commercial timber species are grown, such as teak and mahogany, marketing would probably also be easier and the timber price might be higher. In general, more specialised tree-crop management could be developed. However, applying a more critical view to a comparison of forestry and agroforestry systems, some advantages of agroforestry do seem apparent, as noted in the following examples.

Species interactions and synergies. Various authors have listed types of interactions which may take place in agroforestry and silvopastoral systems, e.g. Hasanuzzaman (nd). For MSA systems, some of the positive interactions include shading and reduction of heat stress, more efficient use of light and aerial space, more efficient use of rooting space, biomass contribution, microclimate amelioration, water conservation, weed suppression and soil conservation. Some potential negative impacts include competition for light, nutrients and water, and allelopathy (phytotoxins). Special cases of positive interactions arise where a species will not survive without another (host) species, a notable case being sandalwood (*Santalum* spp.), and where nitrogen-fixing species are included.

Carbon sequestration. It has been argued that relative to monoculture forestry, agroforestry has particularly high and lasting carbon sequestration. For example, Nair et al. (2009, p. 10) argued that "the greater efficiency of integrated systems in resource (nutrients, light, and water) capture and utilization than single-species systems will result in greater net C sequestration". This could be an important social benefit, although capturing payment for environmental services continues to be difficult for smallholders due to institutional and transaction cost issues.

Land protection. Agroforestry systems with a relatively high canopy and understory plant density can provide greater soil protection than widely spaced timber trees, particularly deciduous species such as teak, which suppress undergrowth and leave surface soil exposed to rain for part of the year.

Early income generation to support growing long-rotation species. Inclusion of fruit and vegetable (including root crop) species in agroforestry plantings provides early income, which can make the growing of longer rotation species financially feasible. For example, there is interest in growing vesi and sandalwood (high-value specialty timbers) in western Viti Levu, intercropped with kava to generate an early cash flow.

Labour utilisation and work sharing. Agroforestry systems producing food products could be expected to provide greater opportunities for women and children to take part in farming, and in the process earn income or contribute to family income.

Crop protection. Multi-species plantings can include trees with strong cyclone resistance, reducing wind damage to other species. Mixtures provide a more diluted habitat and food source for diseases and pests. Shade and wind protection are essential for some species during plant establishment in the tropics. For example, canarium, cocoa and taro have a shade requirement which can be provided by other MSA species, or in transition from coconuts or other tall species.

Biodiversity conservation. Agroforestry can provide a means of protecting indigenous tree species and their genetic resources. Dense plantings can provide both food and habitat for wildlife species.

Tradition and indigenous knowledge. Practising agroforestry allows landholders to follow practices of earlier generations and utilise the skills handed down through generations (e.g. boat building, growing and using medicinal plants).

In contrast to agroforestry, monoculture timber plantations allow large areas to be planted more quickly and maximise production of timber volume. Caribbean pine has been widely planted in Fiji in recent years, and was described by Thaman (2012, p. 90) as "the major species used in reforestation of degraded grassland areas in Fiji and parts of Vanuatu". In north Queensland, Australia, Caribbean pine was found to be susceptible to cyclone damage. Major tree planting currently being undertaken in Fiji seems to focus on forestry rather than agroforestry. This is the case with the large European Union and Conservation International (CI) reforestation projects, in which teak appears to be a preferred species. Notably, the CI project has reported a list of about 30 Pacific island species to be planted on more favourable sites.

ASSESSMENT OF THE IMPORTANCE OF AGROFORESTRY BENEFITS

From a policy and planning perspective, a cost–benefit analysis of agroforestry expansion is desirable.[4] What are the benefits which can be derived from such an expansion, and what expenditure would be required to bring it about? While an extensive list of agroforestry benefits is evident, placing values on these or even ranking their relative importance is extremely difficult.

To support policy formulation, knowledge of the relative economic importance of the diverse contributions of agroforestry is critical. Various methodologies to assist this task have been described in the collection of papers compiled by Alavalapati and Mercer (2004). The importance of sustainable development and triple bottom line performance has been increasingly recognised in recent years.

As observed by Kant and Lehrer (2004), reporting about agroforestry systems has been heavily biased towards ecology, under the rather narrow definition that 'systems' are groups of interacting physical components. This typically fails to include legal, social and economic components. These authors argue that "for the analysis of agroforestry systems, an understanding of a system has to be extended from physical connectedness to physical as well as non-physical components and … to … connections through people's actions in market as well as non-market situations, social norms and sanctions …". Kant and Lehrer (2004) have also drawn attention to the lack of an institutional analysis framework focussed on agroforestry. This appears to be largely due to agriculture and forestry being treated as separate fields, particularly as large-scale specialised production systems developed in the 19th and 20th century, and with the influence of colonial powers and their property rights regimes. A consequence is that agroforestry activity is generally not well reported in national official statistics.

DISCUSSION AND POLICY IMPLICATIONS

Mixed-species agroforestry traditionally played a critical role in food supply in the Pacific islands. As noted by Thaman et al. (2000, p. 24) "traditional agroforestry practices once made Pacific islanders amongst the most self-sufficient and well-nourished peoples in the world". With the decline in prices for copra and sugar, and evidence of senile coconut plantations and abandoned sugarcane plantations, new forms of agroforestry are required to make more profitable but sustainable use of this land. The urgency is exacerbated by the rural–urban drift, high cost of food imports, and adverse economic and community health trends. Fiji and Vanuatu are relatively well endowed with agricultural production capacity, and various government measures are now encouraging agroforestry expansion.

It seems clear that the pattern of land use in Fiji and Vanuatu has in the past been able to adapt

4 Some insights into economic and policy research needs in relation to re-agroforestation are provided by Mercer and Alavalapati (2004, pp. 308–309) in their discussion on 'Gaps and future directions'. An invaluable collection of descriptions of trees and other plants of particular value in agroforestry edited by Elevitch (2006) is available online.

to changes in market conditions and political circumstances, and further changes now appear necessary. Research into appropriate agroforestry systems, planning on how these can be rolled out, and access to sufficient funding and other support measures are needed to support this adaptation.

If a decision is made to strongly promote additional agroforestry establishment, then an assessment is needed of the planting options, obstacles to be overcome and costs which are likely to be incurred. Further biophysical and socio-economic information is needed in planning measures to promote agroforestry expansion in both Fiji and Vanuatu. A starting point is identification of the most suitable agroforestry systems and species for particular sites, in terms of biophysical species–site matching and in terms of the resources, interests and attitudes of landholders. Such an assessment would need to take into account the national government's priorities concerning tree species to conserve as well as areas which require assistance and other policies.

In parallel with identification of agroforestry options, information is needed on the support measures which would be required by landholders for them to maintain or expand their area planted to agroforestry. Of relevance would be the various measures which can be employed to promote agroforestation, and in particular, market-based instruments and provision of information and training. As well, an investigation into the potential sources of financial support is needed. If experience in smallholder forestry elsewhere is any guide, a careful analysis of governance issues and the way in which these promote or obstruct tree planting is also needed.

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2. Modelling approaches for mixed-species agroforestry systems

Steve Harrison and Robert Harrison

Abstract

Given their complexity, the design and evaluation of agroforestry systems has been a challenging task for researchers. A 'triple bottom line' evaluation in terms of financial, social and environmental impacts is called for. This working paper was developed to select a logical and consistent modelling approach for multi-species agroforestry (MSA) systems, with particular emphasis on predicting financial performance. A number of potentially suitable modelling approaches and software packages are reported in the literature. These have typically used third and fourth generation computer programming languages and modern software packages (notably spreadsheet packages). The Australian Cabinet Timber Financial Model (ACTFM) was developed to predict potential returns from small-scale plantations of north Queensland high-value mixed-species rainforest cabinet timbers, for which there was little experience of plantation commercial production. The New Zealand Agroforestry Estate Model (AEM) was designed to evaluate agroforestry in combination with other farm activities. The Agroforestry Modelling Environment (AME) was designed as an object-oriented modelling tool to graphically visualise, construct, integrate and exchange agroforestry models. The AME was subsequently developed into the SIMILE simulation package, designed for building general ecology models. Nowadays, with the continued development of spreadsheet packages (notably Excel), increasing use is being made of this software for forestry modelling. While spreadsheets are widely used in the timber industry, and in forestry research projects, their use for design and evaluation of complex MSA systems is less well exploited. An intuitively powerful approach is to develop MSA financial models in an Excel workbook, with separate spreadsheets within the workbook for individual species. In support of this approach, a suite of financial models for individual species could be developed as modules, which can be combined relatively quickly to evaluate various MSA designs.

INTRODUCTION

Agroforestry has a long history in Pacific island countries (PICs), on farms, in villages and around houses. However, there has been a decline in the area under agroforestry, in large part due to the drive for export-oriented plantation agriculture during the colonial era and the more recent population drift to the cities. Many potential benefits of increased agroforestry planting have been identified, for example in terms of improved nutrition and health, reduction in food import expenditure, reduction in land degradation and conservation of traditional Pacific island tree species and lifestyles.

The focus areas for the ACIAR small research activity (SRA) ADP/2014/013 'Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu' are sugarcane land in western Viti Levu in Fiji and aged coconut plantations on Efate Island in Vanuatu. Questions arise as to what species landholders should grow (and governments should promote) in new agroforestry plantings, referred to by Clarke and Thaman (1993) as 'institutional' agroforestry systems, as distinct from traditional systems that contain small numbers of many species suited to individual household food needs. One component of this research involves determining the likely financial performance of potential new agroforestry plantings, which together with social, environmental and institutional impacts can guide choice of species mixtures. The financial analysis is also intended to help guide the choice of measures which could be adopted to encourage such plantings and levels of financial support which may be required.

Carrying out financial analysis of novel or rarely planted indigenous tree species presents difficulties in understanding and modelling silviculture requirements, obtaining yield and stumpage price data, and model refinement and validation. The challenge becomes even more difficult when modelling mixtures of timber, fruit and nut tree species as well as the various short-rotation and annual food and other species which can be grown with them. In addition, it is recognised that there can be many species interactions in agroforestry systems—a major reason why particular tree and crop mixtures are adopted—and modelling these interactions can be particularly difficult. As stated in Wikipedia (2014), intercropping or growing two or more crops in proximity is designed to "produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilised by a single crop".[1]

While traditional or informal agroforestry systems often comprise a seemingly random collection of trees and other plants, institutional agroforestry systems[2] are generally designed with a systematic planting pattern, such that the areas and planting time arrangements of the various components are identifiable, and in principle, the future annual cash flows associated with each species can be isolated and predicted. Hence, it should be possible to perform a financial analysis on these systems, although a large number of parameter estimates and assumptions may be required.

The yield and resource-use coefficients for particular species may differ when they are grown in mixtures rather than being grown alone, which would lead to differing parameter values in multi-species financial models relative to those of monoculture plantings. This raises questions of how interactions between species in MSA systems are best integrated into financial models.

In terms of research method, an extensive review of the studies mentioned above, and other literature relevant to Pacific island agroforestry, has been conducted. The research objective was essentially to develop a modelling approach suitable for financial evaluation of MSA systems in Fiji and Vanuatu.

Excellent descriptions of many Pacific island tree and crop species are reported in Elevitch (2006). There is extensive literature on the modelling of forestry and agroforestry systems, covering a wide variety of approaches (e.g. Ellis et al. 2004; Godsey et al. 2009; Dayanandra et al. 2002; Alavalapati et al. 2004). There is also a wide literature on the interactions between species in MSA systems (e.g. McDicken and Vergara 1990; Rao et al. 1998).

The next section reviews modelling approaches used to evaluate forestry and agroforestry systems. Literature on the benefits—particularly biological, but also social and environmental—of MSA rather than monoculture systems is then reviewed. Challenges in developing spreadsheet models are examined, and particular features of the chosen modelling approach are discussed. Comments are made about testing model usefulness and validity, and making extensions and refinements to mixed-species financial models.

APPROACHES TO EVALUATION FOR MULTI-SPECIES AGROFORESTRY SYSTEMS

Particularly in the last 25 years, many computer models have been developed which can predict the biological and financial performance of forestry and agroforestry systems, using various computer platforms. This work became available with the development of third generation computer programming languages (3GL), such as FORTRAN, ALGOL, COBOL, PASCAL, BASIC, C and Java. It was further supported by 4GL software, including SAS, SPSS, Stata, Matlab and Prolog. A number

1 The article in Wikipedia (2014) identified four types of intercropping, viz.: mixed intercropping (crops totally mixed in the available space); row cropping (including alley cropping); combining species with differing growth rates and harvest times; and relay cropping (planting different species at different times, where the crop times overlap).

2 Various forms of agroforestry have been identified in the Pacific islands, categorised as plantation-crop combinations, multipurpose trees, homegardens, alley cropping or hedgerow intercropping, taungya, sequential cropping systems, dispersed trees with understory intercropping, silvopasture, shelterbelts and windbreaks, live fences and border plantings, and improved fallow and land rehabilitation (e.g. see Elevitch and Wilkinson 2000, p. 123; Alavalapati et al. 2004, pp. 2–3). In this paper, the primary focus is on the first of these forms, which has also been referred to in the Pacific islands as multi-species agroforestry or MSA (e.g. by Thaman et al. 2000, p. 26).

of spreadsheet packages have also been important for financial modelling, including VisiCalc, Lotus 1-2-3, Quattro and Excel. Nowadays, the Microsoft spreadsheet package Excel dominates the spreadsheet market and has been used extensively in modelling forestry systems.

Ellis et al. (2004) reviewed various 1990s computer-based decision support tools (DSTs) used in agroforestry, including databases, geographical information systems (GIS), computer-based models, mathematical computer models, knowledge-based or expert systems and hybrid systems. Five examples reported by Ellis et al. (2004) and updated by Atangana et al. (2014) are as follows.

1. DESSAP (Agroforestry Planning Model)—a multi-objective linear programming model to assess feasible agroforestry alternatives based on land, labour and cash constraints, developed by Garcia de Ceca and Gebremedhin at Cornell University in 1991.
2. BEAM (Bio-economic Agroforestry Model)—a bioeconomic model to assess physical and financial performance of agroforestry systems, developed at the University of Wales.
3. AEM (Agroforestry Estate Model)—an economic model to evaluate agroforestry in combination with other farm activities, for assessing effects of tree production and physical and financial resources on-farm, developed by Middlemiss and Knowles in New Zealand in 1996.
4. AME (Agroforestry Modelling Environment)—an object-oriented modelling tool to graphically visualise, construct, integrate and exchange agroforestry models, developed by Muetzelfeldt and Taylor for Europe in 1997. AME has apparently now been developed into the SIMILE simulation package designed for building general ecology models, and is available from Simulistics (http://simulistics.com/).
5. WaNulCAS—designed as a "biophysical model of tree–crop interactions based on above- and below-ground resource capture and competition of water, nutrients and light under different management scenarios in agroforestry systems" and available through the World Agroforestry Centre (ICRAF).

Thompson (1999) developed the AGROFARM whole-farm model (apparently on an Excel platform) to assess the financial effects of managing existing native timber on four case study farms in northern New South Wales, Australia. Although not specifically an agroforestry model, it did allow for the planting of various native tree species as well as growing crops and raising livestock on the same property.

Herbohn et al. (1998) reported the development of an Excel forestry model (the Australian Cabinet Timber Financial Model or ACTFM) to predict potential returns from small-scale plantations of high-value rainforest cabinet timbers for which there was little experience of commercial plantation production. A detailed description of the model is provided in Dayanandra et al. (2002, Ch. 13). The ACTFM consisted of linked spreadsheets in an Excel workbook (supported by Visual Basic macros) with individual sheets designed to perform particular functions (e.g. store data, perform calculations and display results including the net present value (NPV), land expectation value (LEV) and internal rate of return (IRR)) for a woodlot containing up to five tree species. Default yield, price and other parameter data were provided, and these could be overwritten by the user. Estimates of pessimistic, best guess and optimistic growth rates (mean annual increments or MAIs) and stumpage prices were obtained for 32 tropical rainforest tree species with potential for plantation use through a Delphi survey of forestry experts. Harrison et al. (2001) used the ACTFM with the @RISK analysis add-on to estimate the financial risk of a three-species mixture, in terms of the cumulative relative frequency curve for NPV.

To extend the capabilities of the ACTFM, Herbohn et al. (2009) developed a whole-farm financial model—referred to as the Australian Farm Forestry Financial Model (AFFFM)—which can be used to evaluate the financial performance of farm tree, crop and livestock production. In developing the AFFFM, it was found that Excel had insufficient capacity to undertake the calculations, hence Visual Basic was adopted. Interesting features of this model were the inclusion of a user-friendly menu system and model validation through continuous interactions with users, replication of previous studies, development of case studies and testing by undergraduate students. Harrison et al. (2004) provided a review of the ACTFM, AFFFM, and a forestry financial model developed in the Philippines, including descriptions of model validation tests.

Alavalapati and Mercer (2004) divided financial or economic methodologies for evaluation of agroforestry systems into: enterprise or whole-farm budget models (nowadays mostly performed with spreadsheet packages and sometimes including discounted cash flow analysis); policy analysis matrix (PAM) models (in which accounting matrices of revenues, costs and profits are constructed for the study of selected agricultural systems); risk assessment models (ranking of competitiveness, efficiency and transfer effects of policies); dynamic optimisation models; linear and non-linear programming models;[3] non-market valuation models (e.g. hedonic price and contingent valuation methods); and regional economic models.

Jeffreys (2004) applied the approach of multi-criteria analysis or MCA (also referred to as multi-objective decision-support systems or MODSS) to conduct a broad analysis of community perceptions about the socio-economic and environmental benefits of a range of alternative forestry options in southern Queensland, Australia. One of the options examined was a silvopastoral system (plantations and grazing). This approach is well suited to policy studies though it does not include an in-depth financial analysis.

It is notable that Muetzelfeldt (1995) commented on the limitations of using computer programming languages such as FORTRAN for developing financial models for agroforestry systems, but recognised the utility of having subroutines in computer programs to represent modules in model development. Muetzelfeldt "presented a framework for the development of a modular system for agroforestry modelling" (p. 224) using the Prolog programming language. It appears that the SIMILE visual modelling environment—with models developed diagrammatically rather than as written lines of text—later arose out of this research. Muetzelfeldt reported a number of advantages for adopting this modular environment: simplification of the task of implementing models and modifying their structure; increased cooperation between modeller and researcher; increased reusability; support for the modelling process (by the software); increased clarity of communication of model structure; and ability to investigate model components separately.

CHOICE OF MODELLING METHODOLOGY AND METHOD OF INTEGRATING INTERACTIONS BETWEEN SPECIES

The above review shows that financial or economic analysis of agroforestry systems, which may include identification of optimal agroforestry systems in terms of the species components, has been performed using general purpose programming languages (including FORTRAN and Visual Basic), simulation modelling languages (such as SIMILE and SIMUL8), PAM (policy analysis matrix) models, dynamic programming (an optimisation method for solving a complex problem by breaking it down into a collection of simpler subproblems), linear programming (as well as related goal programming and mixed-integer programming), and various spreadsheet packages (though nowadays dominated by Microsoft Excel, sometimes with risk analysis add-on software).

Nowadays, a wide variety of computer simulation packages are available for modelling natural systems, in part driven by the popularity of computer gaming. A downside with using simulation languages is that they can require substantial learning time.

Various linear programming models have been developed, which incorporate forestry investment along with other enterprises on farms. This broader approach has the advantage of considering forestry—including mixed-species plantings—in the context of the overall farm business and resource availability.

3 Linear programming is a mathematical method of maximising the revenue or minimising the cost of a collection of potential activities subject to a set of linear constraints. It has been used widely in farm planning. If particular tree or crop species are viewed as the activities, with supplies of land, labour and capital during the critical woodlot establishment years as constraints, and financial analysis has been performed for the individual species, then mixed-integer linear programming can be used to determine an agroforestry species mix which maximises the aggregate NPV. The Solver facility in Microsoft Excel can be used to perform this type of 'portfolio selection' analysis, including having constraints for contingent, mutually exclusive and otherwise related activities, as demonstrated in Dayanandra et al. (2002, Ch. 12).

However, linear programming does involve substantial data collection effort. In terms of the objectives of ACIAR project ADP/2014/013, a more focused analysis of the financial performance of specific agroforestry systems is preferable, although some consideration of the wider farm setting is also needed.

A decision was made to use a Microsoft Excel spreadsheet approach for modelling agroforestry systems in Fiji and Vanuatu because this package is well known to researchers and the community in general, and is relatively easy to use. Excel contains a wide variety of financial functions to aid discounted cash flow analysis, including those needed for NPV and IRR. Also, the Goal Seek facility supports breakeven analysis, the Data Table facility simplifies sensitivity analysis and the Scenario Manager supports comparison of project performance under optimistic and pessimistic sets of parameter values. The ability to trace precedents and dependents assists in checking formulae. The AGROFARM and AFFFM models are examples of how spreadsheet packages can be designed to represent whole-farm businesses, including trees, crops and livestock.

Several other useful features are available in Excel. The Visual Basic programming language allows macros to be created to automate repeated calculations. The @RISK add-on for Excel allows quantification of investment risk, through which the variability of yield, price and other exogenous parameters in a forestry or agroforestry system can be represented as subjective probability distributions, and a cumulative relative frequency distribution, for say NPV, generated.

This choice of an Excel modelling platform is designed to facilitate a modular approach to model development, which has been advocated for example by Muetzelfeldt (1995) and Herbohn et al. (1998). The possibility of having several sheets in the same Excel workbook, with cell references across sheets, creates the opportunity for modules for individual species to be created and linked together in the one workbook.

The approach being adopted is to have the 'front' spreadsheet as the control or summary sheet, with a subsequent separate sheet for each individual species in the mixture. The front sheet could contain all common parameters as well as aggregating performance summary data across each individual species. Any sensitivity analysis for the overall MSA system would be performed in the front or summary sheet.

BENEFITS OF AGROFORESTRY ADOPTION BY SMALLHOLDERS

When integrating financial models or modules of individual tree and crop species into an MSA financial model, it is necessary to examine how the species will fit together in the system. This raises questions of how the performance of species will differ when they are grown together as against when grown as monocultures.

Interactions between species in MSA systems

Agroforestry systems have generally been regarded as providing some positive interactions between species, i.e. more than the sum of the expected outputs which would be obtained if the tree, crop and livestock species were instead grown in separate blocks. Some of the more frequently cited benefits, but also negative impacts, are listed in Table 1.

In terms of biological interactions, two 'projects' may be independent, complementary, competitive, contingent or mutually exclusive, e.g. see Dayanandra et al. (2002, Ch. 1). Viewing the growing of individual tree and crop species as investment projects, positive interactions arise in complementary projects and negative interactions with competitive projects. Some complementarity is to be expected in intercropping, e.g. intercrops are likely to reduce the weed control effort required for trees. A case of a contingent project is sandalwood being contingent on host species. Grazing cattle and growing crop species edible to cattle on the same land are mutually exclusive projects.

Quantifying the yield benefit from growing species mixtures

A measure of the yield gain due to growing species in a mixture rather than as monocultures is the 'relative yield total or RYT' (described in relation to agroforestry by Tofinga 1993) or 'summed relative yield' (applied to mixed-species forestry by Lamb et al.

Table 1. Positive and negative biophysical interactions between species in tropical agroforestry systems.

Interaction	Process
Positive interactions	
Chemical soil fertility—carbon	Increased organic matter through litter fall, root turnover and incorporation of prunings and crop residues
Chemical soil fertility—nitrogen	N fixation, deep soil N capture, reduced leaching
Chemical soil fertility—other elements	P, Ca, Mg, K, generally made more available; Al—binding and detoxification
Soil fertility—physical	Improved soil aggregation, porosity and aeration; reduced soil bulk density; break up of compacted soil layers
Soil fertility—biological	Build-up of soil macrofauna and microbial populations; build-up of mycorrhizal and rhizobial populations; reduced soil insect pests and pathogens
Complementarity	Sharing of growth resources (light, water and nutrients) by trees and crops
Microclimate	Shading, hence reduced soil and air temperature; shelter from cyclone damage; rainfall interception and redistribution
Conservation	Reduced soil erosion and leaching; terrace effect
Biological—weeds	Reduced weed populations; shifts in weed species; decreased viability of perennial weed rhizomes; decay of annual weed seed bank
Biological—pests and diseases	Reduced pest populations and increased pest predator populations
Negative interactions	
Competition	Light, water and nutrient competition
Allelopathy	Release of growth-affecting chemicals into the soil environment

Note: In silvopastoral systems, beneficial impacts include shading and manure deposition, while negative impacts include browsing and trampling, and providing a disease or pest habitat.
Source: Adapted from Rao et al. (1998), and also drawing on McDicken and Vergara (1990), Hasanuzzaman (nd) and Isaac (2008). Isaac (2008) made a distinction between tree–crop interactions (multiple resource utilisation and competition) and facilitation (nutrient cycling and shade).

2005). According to Tofinga (1993), "the RYT index was designed as a measure of the extent to which various crop components shared common resources rather than as a direct measure of yield advantage". Lamb et al. (2005) interpreted relative yield more simply as the ratio of the yield of a species grown in a mixture and grown as a monoculture, and the total relative yield as the sum of these ratios for a species mixture. A similar measure has been described by Kho (1997, Ch. 4, p. 53): "A yield advantage in AF and intercropping systems occurs if the mixture produces more yield from an area of land than can be obtained by dividing that area into pure stands. It is most frequently … quantified by the land equivalent ratio (LER), which is defined as the relative land area in pure stands that is required to produce the yields in mixture. If LER > 1, then the mixture is more advantageous than separate monocultures."

Private and community environmental and social benefits of agroforestry systems

As well as having biological benefits for farmers, agroforestry can have considerable social and environmental benefits for farmers. A major social benefit is the self-employment of the farm family in the various agroforestry tasks, in that the labour input by the family—including women and youths—can be viewed as both a project expenditure item and also a family income item. Further, combining fruit and nut trees and food crops with timber species generates an early revenue stream and lower project peak debt, thus making timber production as a future income 'bequest' more financially feasible. Some Pacific island tree species have colourful flowers, provide dense shading and provide a habitat for birdlife, which can be desirable environmental outcomes for the farm family.

There can obviously be major social and environmental benefits to the wider community of agroforestry on farms and in public areas. These benefits are discussed by Bauer et al. (2003) for an Australian agroforestry and farm forestry program in terms of the 'triple bottom line framework' of economic, social and environmental impacts. In a Fiji and Vanuatu context, community socio-economic benefits can include flood mitigation, lower water treatment costs, more efficient use of scarce land, improved human nutrition when food crops are included, increased local employment opportunities (including for women and youth) and increased opportunities for small business development. Environmental benefits can include watershed protection, improved wildlife habitat and more trees for shading and landscape beautification, including in urban areas. Using the financial model for a particular MSA system could allow costs to be placed on achieving these social and environmental benefits. However, the focus here is on private benefits to growers, and these positive externalities and the costs of generating them are not considered further.

SOME EXAMPLES OF AGROFORESTRY SYSTEMS AND SPECIES INTERACTIONS

In project ADP/2014/013, a number of MSA systems have been observed, suggested in the literature or mentioned in discussions with agroforestry experts. Some insights into the yield interactions between species, as well as social and environmental interactions, can be obtained by considering a few of these species mixtures.

Fiji: Breadfruit + pineapples + cassava—observed on a site visit. Kokosiga Fiji is establishing an area of these three species near Nadi in western Viti Levu, with breadfruit and pineapples in an alternating strip arrangement. There are strong social benefits in that each species provides a food crop quickly; pineapples and cassava in 1–2 years and breadfruit in about 4–5 years. There is moderately wide spacing between species so the biological interactions are limited. The breadfruit trees provide some wind protection, and some prunings from the breadfruit can be used as organic fertiliser for the other species.

Fiji: Vesi + sandalwood + kava—suggested species mix. Vesi (*Intsia bijuga*; kwila) is a valuable carving and flooring timber species with a long rotation (more than 40 years), suitable for growing on relatively dry sites found in the Western Division of Viti Levu. Sandalwood (*Santalum yasi*) is also suitable for relatively dry sites, with an optimal rotation period of 20 or more years, and vesi can provide a long-term host crop. Kava (*Piper methysticum*) is a high-value shrub with a typical harvest age of about 4 years which can be used as a short-term host species for sandalwood; a drink used for social and ceremonial occasions is produced from the roots.

Fiji: Tahitian chestnut + taro—observed on site visit. Taro (*Colocasia esculenta*) was planted as a farm household food crop on the eastern side of, and relatively close to a wild Tahitian chestnut (*Inocarpus fagifer*) stand, in a wet coastal site near Nadi in western Viti Levu. The Tahitian chestnut provided shade (important during establishment) and some wind protection for the taro.

Fiji: Mango + cassava—observed on a site visit. Both species are relatively well suited to sites with a dry winter period of several months. They were being grown as separate blocks but with some wind protection being provided by the mango (*Mangifera indica*) trees for the cassava, and they may be suitable for an intercropping system.

Fiji: Caribbean pine + sandalwood—observed species mix. The growing of sandalwood on the eastern side of a Caribbean pine (*Pinus caribaea*) woodlot has been observed by Thomson (2006). Both species are capable of growing in relatively dry areas and Caribbean pine (identified by Thaman et al. (2012) as the major species used in reforestation of degraded grassland areas in Fiji and parts of Vanuatu) is a suitable host for the high-value sandalwood species.

Vanuatu: Tropical almond (sea almond) + taro + velvet bean—recommended by R. Markham, ACIAR. Tropical almond (*Terminalia catappa*) and taro are suited to moist coastal areas and can tolerate some salinity. A velvet bean (*Mucuna pruriens*) green manure crop could be grown to improve the soil condition for taro. Three crops of taro could probably be grown before the shading and root competition of the tropical almond becomes too high. Tropical almond provides some wind protection and its leaf fall provides some organic fertiliser for the taro crop.

Vanuatu: Canarium + cocoa under coconuts—suggested system. Thomson and Evans (2006) identified these species as well suited to being grown together, and Wallace (2014) described a mixed cropping system with cocoa (*Theobroma cacao*; understorey), canarium (*Canarium indicum*; midstorey) and coconut (overstorey). This mixture would be particularly suitable for replacing senile coconut plantations. Both canarium and cocoa require shading for the first few years after planting (and can tolerate some shading thereafter), and the coconut palms could be progressively removed. Both canarium and cocoa develop extensive root systems, which would limit weed competition. Cocoa is reasonably drought tolerant and can be grown on a wide variety of soils. Canarium is a particularly good windbreak species, and would protect the cocoa, which is prone to wind damage (Thomson and Evans 2006, p. 6).

Vanuatu: Canarium + banana + papaya + root crops—suggested system. Thomson and Evans (2006, p. 1) commented on canarium being intercropped with bananas (*Musa* spp.), papaya, root crops and kava as a mixture with some early revenue. These authors reported that canarium needs at least 50% shading during establishment, and noted that bananas can provide 25–50% shading during the first 3–4 years of canarium establishment. Canarium itself provides heavy shading for other species and is highly effective in windbreaks for other species. Nut production does not occur for about 7 years so revenue generation from horticultural species in the short term is highly desirable. Another canarium agroforestry system suggested by Thomson and Evans (2006) is to combine this species with mango and cocoa. Yet another possibility would be to grow canarium with bananas and pineapples.

Vanuatu: Cocoa under coconuts. In a vegetation study of coconut-based agroforestry systems on Malo Island in Vanuatu, Lamanda et al. (2006) commented that the major tree species found were coconut and cacao, a mixture recommended by local extension services. The coconut palms were ageing and cocoa was a suitable intercrop because of its competitive root system and high shade tolerance.

Vanuatu: Cocoa + sandalwood + annual food crops—site observed on a field visit. Mr Joseph Merit on Epi Island is trialing an agroforestry system on regrowth land he has cleared by chainsaw. Some shade trees are left and cacao, sandalwood (*Santalum austrocaledonicum*) and fruits and vegetables are planted simultaneously. Salad vegetables are available in the first year and root crops (sweetpotatoes and yam) as well as papaya and corn are grown as cash crops for about 3 years. Cocoa provides a long-term host for sandalwood, which is to be harvested at an age of about 20 years, at which time a cocoa monoculture plantation will remain.

Vanuatu: Taro under coconuts—observed by IPGRI (2001).[4] This relatively simple agroforestry system, suitable for moist lowland planting sites, takes advantage of the wide spacing of coconut palms and the relative shade tolerance of taro, a high-value food crop.

Vanuatu: Cattle under coconuts—observed on a site visit on Efate Island. Mature beef cattle were observed grazing buffalo grass in an aged and relatively unproductive coconut plantation. The cattle played an important role in weed control (other coconut plantations in the area were becoming overgrown with tree and vine weeds) as well as providing some income annually.

If interactions between species in MSA systems are recognised, then questions arise as to how the extent of interactions can be estimated and be integrated into financial models of agroforestry systems. While many potential sources of positive interaction can be recognised, estimating their individual or collective impact could be extremely

4 According to IPGRI (2001, p. 9), "in Samoa, an evaluation of potential coconut-based farming systems, based on current farmer practice and research station trials, showed that banana, cocoa, fruit trees, kava.., taro, vegetables and yam could be grown successfully under coconut palms. ... In Tonga, intercropping taro, sweet potato... and tomato with the preferred tall coconut types generated additional income … Research began in Vanuatu on intercropping coconut with banana, cassava …, maize, kava, sweet potato, taro, vegetables and yam."

difficult. A first question to be asked might be: which are the most powerful interactions, or sources of the greatest benefits, from mixing species?

Favourable interactions noted in the potential agroforestry systems outlined above include microclimate benefits, particularly shading benefits during intercrop establishment, as well as shelter of intercrops by upperstorey species from severe cyclones which are frequent in the Pacific islands and which can cause catastrophic yield loss. Shading during establishment years could be provided with shadecloth, but growing a productive shading species would seem to be preferable financially. Another likely benefit is a reduction in surface erosion due to protection by a more dense vegetative cover and leaf litter, which could lead to a long-term productivity increase.

Another potential benefit of agroforestry (listed in Table 1) is reduced pests and diseases, e.g. from barriers created between susceptible species. Growing a mixture of species could reduce the amount of agrochemicals needed in growing species such as cocoa and taro, for which pests and diseases can cause major crop losses. In general, it is likely that agroforestry, when combined with other crop protection measures, could reduce the amount of agrochemicals needed. As commented by Thomson and Evans (2006, p. 10) in relation to cocoa production, "preventing or managing pests and diseases requires good agricultural practices including maintaining tree height at less than 4 m … phytosanitation, application of organic or chemical fertilisers, and Integrated Pest Management (IPM)."

It is possible that fire risk could be reduced if relatively fire-resistant species, or species requiring more intensive land management, are included in the species mixture.

In the case of sandalwood, other tree and crop species, and pasture in silvopastoral systems, can provide some host species function. Overall, the favourable interactions appear to often be one-directional, i.e. 'facilitation' of one species by another, as described by Isaac (2008).

Species interaction in relation to planting design and spatial separation

The extent to which species interaction benefits arise will depend on the closeness of species in the planting layout. As distinct from the intimate mixtures in traditional agroforestry systems, such as homegardens, institutional agroforestry designs typically involve planting in rows, sometimes with species mixed within rows and sometimes with alternating single-species rows. Such row planting arrangements are common for mixed timber species plantings (Appendix A). Depending on the row spacing, the species interaction could be small. In the Kokosiga planting in western Viti Leva, breadfruit is planted in single rows with three-row strips of pineapples (a species that does not requiring shading during establishment) and the resource sharing and microclimate benefits would probably be small.

An extreme case of separation is noted in the Conservation International planting in Ra province of Viti Levu. As reported by CI (2013, p. 41), "a total of 1,135 ha are being reforested with a mix of native species and teak. … Since project inception (up to the end of March 2013), a total of 851.56 ha have been planted … , representing 197,646 seedlings planted. Teak seedlings are planted along mid-slope as they are more suited to the harsh environment and on plots that are entirely comprised of mission grass (*Pennisetum polystachyum*). Native seedlings are planted at the bottom of the ridge, near waterways and remnant forest patches. From pilot plots we have found out they tend to do well in sheltered or less extreme environments." In this situation, there would be little if any biological interaction between teak and the approximately 30 'native species' chosen for the project.

Ballpark estimates of interaction benefits

Estimation of the magnitude of species interaction benefits is clearly difficult. In this regard, Lamb et al. (2005, see Appendix A) estimated the 'summed relative yield' for pairs of species, where one species is grown between rows of another species. The yields are relative to what would have been achieved if the species were grown in monocultures. Over six comparisons, a mean relative yield of 1.28 and range of 0.90 to 1.62 were found.

It would be useful if such estimates could be obtained for pairs of priority Pacific island species. A first source would be a review of published research. Conducting new field trials may be possible to obtain empirical estimates of interaction benefits for particular agroforestry species mixtures. Observations could also be made of existing on-farm agroforestry systems although many confounding factors would likely be present. Yet another approach would be obtaining subjective opinions of experts familiar with Pacific island species.

INTEGRATING INDIVIDUAL SPECIES AND THEIR YIELD INTERACTIONS INTO A MULTI-SPECIES FINANCIAL MODEL

When developing an agroforestry financial model on a Microsoft Excel platform, some options are possible for combining the analyses of individual species.

Treating species' financial performance as additive. The species could simply be regarded as independent, such that the costs and revenues of stand-alone planting are added, without allowance for interaction. This would likely be a conservative approach in terms of revenue generation. To make allowance for such bias, a scenario analysis could be conducted, in which one scenario is to include yields of species likely to benefit being increased by say 10% or 20%. If this scenario changed the outcome from a negative to positive NPV then there would be reason to explore the species interactions more fully.

Applying a common adjustment to yield performance of all species. An approximate and probably subjectively estimated overall yield increase could be adopted, with a common factor applied to each species in the mix. However, often particular species are grown in multi-species planting to facilitate others (e.g. including a legume species to support species with high nitrogen requirements), and yields of all species are not likely to increase by identical percentages, and may actually decrease for one or more species. This approach to modelling could lead to misleading recommendations to growers.

Treating two or more species as a single unit. Where there is clear synergism between two particular species, the financial analysis of these species could be combined in a single spreadsheet in the workbook, designed to represent their collective performance, including interaction benefits. An example would be where sandalwood is grown and is dependent on a host species, e.g. Caribbean pine, a casuarina species or a citrus species.

Making adjustments to parameters of individual species in the overall MSA system model. Making adjustments to yield parameters of each individual species in the overall MSA system workbook would normally be the most appropriate method to deal with interactions between species. It would also be an easier approach to communicate to information providers and model users. The yield adjustments to the species modules would probably be made before they were integrated into the mixed-species financial model.

In the ACIAR project, the decision was made to adopt the last of these options, and adapt yield estimates to those likely to be achieved by each species in the agroforestry system, when developing the species spreadsheets for the overall MSA system.

It should be noted that changes to yields could in turn lead to changes in dependent parameters, including harvesting and post-harvest processing time requirements, and transport and marketing costs. It could also be necessary to allow for changes in particular yield, fertiliser input or other parameters over the project life (i.e. the number of years until the species with the longest rotation is harvested) if soil improvement or reduction in land degradation was expected to occur. Further, there could be changes in the quality of produce, which might lead to price changes.

SOME FEATURES OF THE MODELLING APPROACH

A modelling approach or template has been developed to predict the financial performance of MSA systems. The information compiled for financial analysis of a particular MSA system is integrated in a single Excel workbook. The workbook structure is relatively simple, an important feature being the linking of a front or summary spreadsheet with the sheets for individual speciesets for individual species.[5] Other features include the use of financial functions, one-way and two-

5 Instructions for making cell references between spreadsheets can be found under *Linking workbooks 2010 in Excel* in the Excel help menu.

way tables for sensitivity analysis, the goal function for breakeven analysis and the scenario analysis facility for examining the impact of varying groups of parameters simultaneously. The modelling approach has a number of useful features, as discussed below.

The front or summary spreadsheet

All the general parameters—those common across all species in an agroforestry system—are included in a single sheet in the workbook; the front or summary sheet (Sheet 1). This spreadsheet contains overhead costs (e.g. for site clearing, land rental, purchase of tools and equipment) and parameters common to all following sheets, for example the wage rate, the exchange rates between currencies, the discount rate and the marginal rate of tax (if relevant). The area allocated to each species, tree or plant spacing between and within rows, yield and product price would also be included in the front sheet. The front sheet integrates the annual cash flow information for individual tree and crop species. It contains a summary of annual cash flows, estimates of NPV and other performance indicators, and annual labour input required for each species.

Spreadsheets for individual species

A separate 'species' sheet linked to the front sheet is created in the workbook for each component species of the agroforestry system. Species sheets are required for each timber, fruit, nut or multi-product tree, and for palms (e.g. coconuts), bananas,[6] annual fruits and vegetables, and green manure crop species. Some information could be listed at the top of species sheets, such as common and scientific names, type of species (e.g. timber tree, nut tree, fruit tree, palm, annual plant, green manure crop) and perhaps suitable land categories (adapted from Thaman 1993[7]). Parameters which apply only to a particular species are placed in the spreadsheet for that species, e.g. harvest age of timber trees. As work rates will in general vary depending on type of tree (e.g. more time is required for planting fruit trees than timber trees) or crop, and stage of growth (e.g. low pruning versus high pruning), it will generally be preferable to place these in the sheets for individual species.

Avoiding repetition of common parameter values

Including parameter values which are common across species in the front spreadsheet reduces the effort in developing spreadsheets for individual species, helps ensure consistency in parameter values and simplifies revisions of parameter values. Such revisions may be required due to, for example, the availability of improved data on yields, availability of better performing varieties or product price changes over time. A particular case of common parameters across species is that of currency units. Some parameters will change from one year to the next. Sensitivity analysis will provide a guide to the impact of price changes but updating of some parameters will be desirable if continued use is to be made of the financial models over time.

Promoting consistency across species modules

The arrangement of a master spreadsheet and separate spreadsheets for individual species ensures some discipline on using a consistent structure of financial models across individual species, e.g. in terms of sequencing parameters and choosing units of measurement.

Data groups and sequencing in species sheets

The sequencing and format of parameters for each individual species has been made as consistent as possible in the species modules developed to date. In general, the arrangement has been to list the physical parameters in the time sequence in which they become relevant, then the financial parameters in the order in which they relate to the physical parameters, then the cash flow table and performance criteria, followed by a list of some major assumptions made in the species sheet.

6 Botanically, the banana is a herb, growing from a corm, with a pseudostem.

7 Thaman (1993) identified "eight major agroforestry land-use zones" in Fiji, namely: (1) the village site; (2) the areas surrounding the village; (3) agricultural lands, including active gardens and fallow areas on the alluvial flats; (4) agricultural lands, including active gardens and associated fallow on rolling colluvial and mountain soils of the uplands; (5) secondary forest area on both alluvial flat and upland areas; (6) dense primary forest; (7) scattered fenced beef-cattle pastures; and (8) riverbank or riparian areas.

Aggregation of area planted across species

In agroforestry systems, the total area planted is not necessarily the sum of the areas of each species planted. If there is intercropping then in effect two species can occupy the same area of land. If there is sequential harvesting of species, more space can become available to longer rotation species. Examples would be where pineapples are grown between rows of breadfruit while the latter is small, and where whitewood and flueggea (poulumi, namamau) are planted together but with early harvest of fluggea for poles or posts. In contrast to models of mixed-species timber plantations (e.g. the ACTFM), MSA allows for total area utilised to be greater than the sum of areas if the species were planted in separate blocks. Some land could in fact be allocated for non-production uses, e.g. vehicle and walking tracks, snigging tracks, log collection areas and other temporary storage areas, but this has not been allowed for in the modelling.

Ability to add or delete species modules

A particular feature of the modelling approach is that a suite of financial models for individual species (species modules) is compiled for any agroforestry system, which may include priority tree species (producing timber, fruit, nuts or a combination of products) as well as semi-perennial (short-rotation) and annual crop species. The financial models for individual species are portable in the sense that the sheets can be copied into other workbooks to produce different species combinations. Once species financial analysis modules have been developed, these can be added or deleted from an overall model relatively easily, simplifying the development of new MSA system models. A species can be deleted simply by removing the module for that species or assigning it an area of zero hectares in the front spreadsheet. As more species modules are developed, it will become possible to develop a wider variety of MSA models.

Default and user-specified parameter values

The models being developed contain large numbers of physical and financial parameters, e.g. estimates of labour requirements for establishment, maintenance, harvesting and post-harvest processing for various forestry and crop species, yield (or yield profile) estimates and production cost and product price estimates. For users of the models who consider that different parameter values would be appropriate in a given planting situation, it is a simple matter to override any default parameter estimate with a different value. This applies to both common parameters in the front sheet and to parameters in spreadsheets for individual species.

Convenience for performing sensitivity analysis

Parameters for which financial performance of the agroforestry system is thought to be most sensitive need to be specified as common parameters in the front spreadsheet. Having parameters which are common across species in the front spreadsheet facilitates sensitivity analysis of the overall agroforestry system.

SOME COMPLEXITIES IN MULTI-SPECIES MODEL DEVELOPMENT

Some challenges remain in improving the financial modelling approach, and these are briefly reviewed below.

Modelling interactions between species. While there is considerable agreement on sources of interactions between species in agroforestry systems, quantifying the interaction effects remains a major challenge. A possible approach is to develop relative yield factors, as described by Tofinga (1993) and Lamb et al. (2005).

Variations in modelling for individual species. Within an agroforestry system, a particular species could be grown in differing arrangements, e.g. different varieties, single planting time versus staggered planting, differing row spacings, growing in full sunlight versus partial shading or having differing harvest schedules. The extent of value-adding is also likely to vary between growers and planting sites. For example, trees could be sold at stump or debarked and sawn into boards by the landholder, various levels of processing (husking, shelling, drying) could be done or not done on-farm for nut species, and processing could be carried out for some species (e.g. cocoa) by a local grower cooperative. These variations could be accommodated by treating the separate arrangements as distinct activities, with multiple sheets (modules) developed for them.

Dealing with performance variation between planting sites. Tree growth and resource inputs can be expected to vary between sites depending on climate, soil type and other factors. The financial models are being developed for planting trees and other species on sites reported to be suitable for these species. However, if there is considerable performance variation between sites then it may be necessary to include site factors in the financial modules for individual species.

Treatment of common versus species-specific costs. Some of the capital outlays in setting up an agroforestry system—particularly site clearing and purchase of tools and equipment—would be included in the front spreadsheet. On the other hand, some outlays would only apply to particular crops, e.g. facilities for on-farm processing and storage. How to allocate overhead costs between species requires decisions when modelling MSA systems. The allocation would not affect the overall financial performance of the species mixture but would affect the apparent contribution of each species.

DEVELOPING A COLLECTION OF SPECIES FINANCIAL MODULES

Developing spreadsheet modules has proved to be a time-consuming task, initially requiring about 60 hours per species including literature review, consultation with foresters and other experts, and field visits. Much of the time has been spent understanding the species and production systems. Developing yield profiles for nut and fruit species has proved particularly time consuming. A number of financial models for tree species have been developed (e.g. for breadfruit, sandalwood, canarium and cocoa), and it is envisaged that over time further species spreadsheets will be developed and hence be available as modules of MSA financial models. Initial attention will be given to species for which government and other agencies in Fiji and Vanuatu attach high priority. Once these modules are available, the task of developing agroforestry systems models will then become the research focus.

As tree species modules have been developed, the more useful literature sources become known as do standard rates for particular activities (e.g. work rates and contractor costs), making it easier and less time consuming to develop financial models for other species. Where two species in a mixture are both timber species, they can be expected to have a number of parameters in common.

Developing financial models for short-term species (e.g. pineapples, bananas, cassava, kava and pongamia) and annual crops is proving to be much simpler than for long-rotation tree species. Financial models are already available for many annual or short rotation species, e.g. the gross margins budgets of Leslie (2013) for the sugarcane land area in western Viti Levu, Fiji. While some modifications are required to adapt gross margins budgets to crop modules in a discounted cash flow analysis context, this requires far less effort than developing new financial analyses from scratch. A problem arises in that cost and revenue parameters in discounted cash flow (DCF) analyses and annual budgets can quickly become dated, especially during periods of rising prices. Approximations can be made by adjusting the cost and revenue parameters for inflation by multiplying by the change in a consumer or producer price index since they were developed. However, for greater precision, it is necessary to obtain more up-to-date financial parameter data.

APPLICATIONS OF THE MULTI-SPECIES FINANCIAL ANALYSES

Financial analysis certainly does not provide the full picture for decision-making with regard to agroforestry promotion—social, environmental, legal and policy aspects also require analysis—but financial performance cannot be ignored. There is an obvious need to design and apply a reasonably rigorous approach to estimating financial performance of agroforestry systems.

Potential application areas for MSA financial models include policy support, as an extension tool and as a decision-support tool. Some policy areas include determining:

- what agroforestry systems are financially viable in terms of making a positive wealth contribution to

landholders, and in terms of landholder resource availability;
- the financial trade-off between promoting species of high conservation value and those designed mainly for income generation;
- how much assistance (financial or in-kind) landholders would require to be able to establish particular agroforestry systems;
- the extent of labour commitment which would be required for particular species mixtures; and
- the timing of financial or in-kind assistance required for landholders to achieve financial viability in agroforestry investment.

Multi-species financial models can be used in promotion of agroforestry adoption once sufficient confidence is built up in the reliability of these models. In this context, the models can be applied to evaluating agroforestry establishment on new sites or evaluating incremental changes to agroforestry (such as introducing or replacing species) at an existing agroforestry site. One element of extension could be to advise on the area of planting that is likely to be manageable in terms of finance, labour and other inputs. In terms of decision support, experience indicates that few landholders have the ability or inclination to use financial models and that extension officers are likely to be the main model users.

Landholders engaged in subsistence farming or cash cropping in general are often forced by their circumstances to adopt a short planning horizon. Even in the tropics, most timber tree species have a harvest age (and hence payback period) of more than 10 years, and many more than 25 years. In these circumstances, the NPV and payback period of agroforestry systems may be of little relevance to a landholder's tree planting decisions. What may be of more critical importance to the landholder is the financial impact (the project balances) and the labour requirement profile during the early years of their plantation.

MODEL TESTING OR EVALUATION

No symbolic model can be expected to be an exact replication of the real-world system it is designed to mimic. This difficulty is particularly apparent when modelling bioeconomic systems as complex as MSA systems. Two relevant questions are: how reliable or precise is the MSA financial model for its intended uses; and how can the reliability of the model be tested and be improved? In the current ACIAR project ADP/2014/013, the extent of agroforestry financial model development has been constrained by the project budget, timelines and limited number of Fiji and Vanuatu field visits. Initial versions of financial models have been developed mainly through literature review, experience in forestry financial modelling in other countries, a few weeks of in-country visits and some advice from project partners. The species interactions and relative yield factors in particular lack empirical support. While some comments on the models have been provided by people familiar with some of the species, much more critical assessment of the structure of the models, the parameter estimates and the estimated performance criteria is required before the models could be used confidently for policy guidance or as decision-support tools.

The MSA models have been developed mainly to screen species mixtures in terms of financial viability, and to provide estimates of the resource requirements (particularly labour and finance) as a guide to what support levels may be needed to promote wider agroforestry adoption. In general, it can be expected that the prototype models will be more reliable for ranking alternative policies than for predicting performance levels (e.g. return to labour, peak deficit, payback period and NPV) in absolute terms.

Various methods have been developed for validation of systems models, including statistical tests and tests of 'face validity' (subjective assessment by subject area specialists). While such testing is highly desirable, experience reveals that confidence in a model really only builds up as the model is used—and progressively refined—in a number of applications over time.

SOME POTENTIAL IMPROVEMENTS TO THE MODEL APPROACH

A number of potential extensions and refinements to the Excel workbook platform for modelling agroforestry systems are discussed below.

Conducting surveys to obtain landholder and expert opinions about agroforestry systems

It is understood that some surveys have been conducted on landholder attitudes to MSA in Fiji and Vanuatu, but to date no survey reports have been identified by the research team. Findings of these studies, and further sample surveys or collections of case studies of mixed tree and crop planting by landholders in Fiji and Vanuatu, would help understand landholders' preferences and likelihood of planting agroforestry systems, their information needs and attitudes to assistance measures. This could be accompanied by an open-ended survey of key informants (i.e. experts in the Pacific Community (SPC), universities, government departments and NGOs). It would probably be desirable to seek the assistance of the market and value chain research team to recruit interviewers, select respondents and develop questionnaires.

Refining parameter estimates

Various approaches are available to refine the parameter estimates in prototype financial models. An example of the use of the Delphi survey technique to estimate harvest age, timber yield and stumpage price of lesser known or novel tree species in northern Queensland is provided in Dayanandra et al. (2002, Ch. 13). In that labour is a major cost in financial modules for tree and crop species, a Delphi survey of work rates for tree and crop planting, silvicultural and harvesting and post-harvest activities would be particularly useful for improving cost estimates in financial modelling. A draft survey instrument has in fact been prepared for this activity. A survey of landholders would also be useful for obtaining estimates of labour times, as well as annual costs and revenues, for agroforestry species, based on their farming experience.

Integrating environmental and social impacts

It is possible that the modelling approach developed in project ADP/2014/013 will be extended from a financial analysis for individual landholders to a more broad-based economic analysis, explicitly including costs and benefits of community impacts. Given the constraints on project time and funds, this may need to be limited to a 'benefit transfer' approach rather than original non-market valuation surveys. An alternative approach, if the agroforestry activities needed to achieve particular social and environmental outcomes could be identified, would be to use the financial modelling platform and modules to estimate how much expenditure would be needed to achieve these non-market benefits.

Adding risk analysis for a species or an overall agroforestry system financial model

Various risk analysis add-ons are available for Excel, some as freeware, although the rather expensive @RISK add-on is probably the most powerful and most frequently used. With this add-on, the user specifies probability distributions (normally estimated subjectively) of the parameters of the financial model expected to have the greatest impact on overall financial performance (typically NPV). The financial analysis is performed multiple times, and in each replication, a set of random values is drawn from the estimated probability distributions and a new NPV estimate is obtained. Graphing the relative frequency distribution (approximating a probability distribution) of NPV then provides information on the likelihood of various ranges of NPV, e.g. a negative level, an acceptable level and the most optimistic level. That is, instead of having a single point estimate of the NPV, a species (or agroforestry system) risk profile is obtained.

Improving the yield modelling

The simplest approach to representing yields of agroforestry species other than annuals is to estimate mean annual increments (MAIs) for timber yield and linear increase then constant yield levels for fruit and nut products. An attempt has been made to develop yield curves in some of the financial models for individual species developed to date. These multiple-parameter time series models are fitted using the non-linear programming capability of Excel. Availability of more field trial data would allow improved yield modelling and perhaps inclusion of site factors in the yield equations.

Estimating a matrix of relative yields

The relative yield factor approach reported by Tofinga (1993) and Lamb et al. (2005) quantifies the yield interactions between pairs of species in mixed-species plantings. Ideally, tables of relative yield factors would be used for MSA systems. By drawing on field trial findings and subjective assessment by forestry and agroforestry experts (perhaps using the Delphi survey approach), it may be possible to obtain ballpark estimates of these factors for particular species mixtures and management systems.

Forecasting prices for agroforestry products

As the prices which growers can receive for their agroforestry products are critical factors for the financial viability of agroforestry systems, and the levels of these are 'uncertain future events', it would be useful to carry out some systematic price forecasting (if this is not already done by Fiji and Vanuatu statistical bureaus or research agencies). Current price analysis has been used in the financial modelling for individual species, which makes the simplifying assumption that prices of all inputs and outputs change over time at the same rate, however it may be possible to improve on this by gaining some indication of future relative price movements.

Development of a decision-support system tool

Agroforestry system financial models could be developed into decision-support system tools, as has been done for example by Herbohn et al. (1998) for the ACTFM mixed-tree-species model and Herbohn et al. (2009) for the AFFFM agroforestry model. The addition of aids to make models easier for farmers and extension offices to use can be expected to increase their use and their influence on decisions. Support facilities for users can include simple menus to navigate through the financial model, error trapping in input data, help files, sophisticated output graphics and other features. Model developers usually need to work with a programming expert to develop these facilities. Development of macros in a programming language such as Visual Basic or C+ may be required.

DISCUSSION AND CONCLUSION

A modelling template has been developed to predict the financial performance of MSA systems. The template integrates all of the financial models developed for the group of tree and crop species included in a particular MSA system in a single Excel workbook. The component species are entered as individual sheets in the workbook. The integration of species submodels or modules combined with a common set of parameters in the front (or summary) sheet allows considerable time economies in model development and enhanced flexibility for sensitivity analysis and 'what if' testing of predicted agroforestry system performance. This could be particularly important when evaluating a number of potential agroforestry systems to support a regional or national agroforestry expansion project.

While some multi-species forestry models—including the AGROFARM model and the AFFFM—have been designed to evaluate forestry investments in the context of the whole farm business, including crop and livestock production, such a broad approach has not been considered appropriate in this study. Rather, the emphasis is on providing greater analysis detail for mixtures of tree and crop species.

The choice of modelling approach will provide a relatively simple platform for developing financial models for MSA systems, testing the robustness of the financial (and potentially other) benefits generated, and experimenting with the species compositions of the systems. As with any systems model, while some testing of reliability can be conducted during model development, in general confidence in a model is built up over time as it is used in various applications and by various people.

It must be stressed that the MSA system financial models being developed will not be commercial products for business applications, but rather prototype research tools. Considerable testing and trial applications would be required before a high level of confidence could be built up about the financial performance estimates. Further, at this stage the spreadsheet modelling is quite basic, although it would be possible to develop the modelling approach further, to become a financial expert system to aid agroforestry policy and landholder decision-making. A number of potential refinements to the modelling approach can be identified. Some of these, including further data collection from landholders and agroforestry experts, are recommended for any future project. Others—including development of total yield factors and increasing the user-friendliness of financial models—are really suggestions to be examined further.

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APPENDIX A. SOME RELEVANT FINDINGS FROM THE COMMUNITY RAINFOREST REFORESTATION PROGRAM IN TROPICAL NORTH QUEENSLAND, AUSTRALIA

In recent decades, a series of planting schemes have been introduced for tropical rainforest tree species in northern Australia (principally Queensland), including Trees for the Everton and Atherton Tablelands (TREAT), the Wet Tropics Tree Planting Scheme, the Forestry Plantations Queensland joint venture scheme, Tree Care, Landcare (a national community tree planting program) and the Community Rainforest Reforestation Program (CRRP), with a total area of about 45,000 ha on state government-owned land and about 7,000 ha on private land (Vize et al. 2005).

The CRRP was a notable program of mixed-species planting, running from 1992/93 for about seven years, and commencing with a planting list of about 150 potential species, which was progressively narrowed down to about 50 main species. Many of these species were recognised as having cabinet-wood timber of particularly high value but only one (hoop pine, *Araucaria cunninghamii*) had been grown extensively in plantations and little information was available about expected growth performance of the others. The stimulus for planting rainforest timber species on private land arose after the gazettal of the Wet Tropics World Heritage Area covering about 8,940 km² between Townsville and Cooktown in north-east Queensland. The Cooperative Research Centre for Tropical Rainforest Ecology and Management (Rainforest CRC) was established at about the same time as the CRRP and continued for about 13 years, the CRRP providing opportunities for some of its research activities.

Although the CRRP was restricted to mixtures of timber species, it provides some lessons for agroforestry. The climate is relatively similar to that of Fiji and Vanuatu. Cairns has a latitude of 16.95°S, slightly closer to the equator than Nadi in Fiji (17.48°S) and Port Vila in Vanuatu (17.75°S), and an annual average rainfall of 1,992 mm, which is slightly higher than that in Nadi but lower than that in eastern Viti Levu and in Efate Island in Vanuatu. A major thrust of the research undertaken by the Rainforest CRC—reported by Erskine et al. (2005)—concerned the establishment, management, biodiversity, species interactions and socio-economic aspects of mixed tree species plantings.

In terms of species types and planting arrangements, it is noted by Bristow et al. (2005, p. 87) that "Most CRRP plantations are mixed species stands consisting of eucalypts or rapidly growing rainforest pioneer species together with early or late successional rainforest species and historically well-recognised 'rainforest timbers' … In earlier plantings … species were mixed along rows whereas after 1995 the general configuration was a row of single pioneer species alternating with a row of mixed later-successional rainforest species". There is relatively little overlap with the tree species traditionally grown in the Pacific islands. Lamb et al. (2005, p. 131) noted that "the spatial arrangement of these 'mixed' species plantations included sections of monocultures, rows of single species and/or arbitrary plantings of species in and between rows."

Lamb et al. (2005) examined the potential advantages of mixed-species plantations, concluding that stand productivity is increased due to "differential resource use" from component species having differing phenologies, with highest resource demands therefore taking place at different times of the year. Also, differing species root and crown architectures lead to different spatial demands for resources. Further potential advantages noted were improvement in tree nutrition when nitrogen-fixing species are included, faster leaf litter decomposition and nutrient cycling with mixed species, and reduction in insect and pest problems because pest target species are more dispersed in space.

3. Evaluating the financial performance of novel tree species for forestry and agroforestry projects in Fiji and Vanuatu

Steve Harrison

Abstract

This paper examines the application of investment project analysis (IPA) to small-scale plantations of novel tree species in areas of degraded or underutilised land in Fiji and Vanuatu. Growing a small woodlot or agroforestry stand can be considered as a type of investment project. Because tree species can take many years to generate income, application of discounted cash flow (DCF) analysis is appropriate. This paper concerns the application of DCF analysis from the perspective of IPA, as distinct from social cost–benefit analysis (CBA). In IPA, relevant cost and revenue items for the landholder are identified, and annual net cash flows (annual project revenue less capital outlays and operating costs, for the difference between the with-project and without-project cases) are computed over the project life, which depends on the longest species harvest age. In evaluating the financial acceptability of a forestry or agroforestry project, the performance criteria of net present value, internal rate of return, peak deficit and payback period are useful. Some topics treated in detail include: constant versus current price analysis, the concepts of opportunity costs and sunk costs, determining the discount rate, cash flow variables that are most difficult to estimate (including work rates, labour costs, plant protection costs, market and farm-gate product prices, yield estimates or yield curves, post-harvest processing needs and costs) and testing the financial model (verification, validation and sensitivity analysis). A distinction is made between returns to capital and to other resources (particularly labour and land). An example of a Microsoft Excel spreadsheet for a particular forestry species (*Flueggea flexuosa* or poumuli) is presented and some of the important spreadsheet formulae explained. A reliable evaluation of the costs and returns to growers from investment in agroforestry is critical for developing policies to support agroforestry. Conversely, CBA would be appropriate to determine what level of expenditure is justified to support agroforestry expansion from a social or national perspective. This would require estimation of the broader social costs and benefits of agroforestry expansion for timber and food production but also social and environmental benefits (e.g. protection or improvement of riparian and coastal areas).

INTRODUCTION

Substantial areas of underutilised land suitable for forestry and agroforestry appear to be available in Fiji and Vanuatu. A wide variety of Pacific island tree and crop species could be grown in these countries, as single species woodlots or in mixed-species agroforestry plots. Expanded planting of these trees and crops has the potential to reduce food prices, generate revenue from exports, and improve community health and wellbeing. Currently, there appears to be little information available about the likely financial performance of various tree species not widely used in forestry and agroforestry plantings. To determine whether expansion of forestry or agroforestry is desirable from a landholder perspective (individual or community group), investment project assessment (IPA) is needed. To determine whether such investment is desirable from a wider community perspective, particularly when government expenditure is also required, the appropriate economic analysis approach is social cost–benefit analysis (CBA).

Financial analysis must necessarily be designed to support the information needs of government and investors (including farmers). An indication is obtained of the financial viability (whether investment would be worthwhile) and financial feasibility (whether the investment is financially possible) of new plantings on degraded and relatively unproductive land. A positive net present value (NPV) and internal rate of return (IRR) greater than the cost of capital are indicators that an investment is financially viable or would add to the wealth of the investor in the long term. Annual project balances and the peak deficit indicate the financial commitment required, and over what period, to make new plantings financially feasible.

The analysis does not reveal whether landholders will take up a planting 'investment'—this is a matter of attitudes, goals and personal decision-making—but it does provide some guidance about how much assistance might be needed and for how long, in a support package. Financial analysis also does not reveal whether a subsidised agroforestry assistance program is a wise investment by a government. Social CBA is necessary to address this decision. In CBA, additional estimates are made of social and environmental benefits and costs, which tend to be positive and sometimes large in forestry and agroforestry projects. The way in which cost and benefit items are valued, what categories are included, and the discount rate differ between IPA and CBA.[1]

This working paper examines the steps required in the first of these analysis types, and in particular the application of IPA to small-scale plantations of novel tree species in areas of degraded or underutilised land in Fiji and Vanuatu. The notes have been prepared in part to assist in developing a shared understanding of forestry and agroforestry financial modelling by the research team conducting two ACIAR small research activities (SRAs) in Fiji and Vanuatu. In particular, the project performance criteria are explained, and relevant cash flows are identified, as well as Excel spreadsheet development, data collection and model validation.

SELECTING FORESTRY AND AGROFORESTRY SYSTEMS FOR EVALUATION

In recent years, and following considerable deforestation, development of timber plantations has become an important policy in Fiji and Vanuatu.

Agroforestry has been practised in the Pacific islands for thousands of years, but contracted during colonial times with the emphasis on large plantations producing commodities for export. More recently, with increasing urbanisation, homestead and village agroforestry have become important. Further, there has been strong research interest in the last 30 years in expansion of agroforestry based on Pacific island tree species and including food-producing trees and horticultural crops. In part this is driven by concern over the cost of food imports and by community health issues associated with poor diets.

A wide range of agroforestry systems can be observed, with choice of species depending on climate, land type, household needs, landholder preferences and farming skills, and market opportunities. Financial considerations, ecological impacts and land-use policy also influence species choice. The type of agroforestry system most suitable for a particular land unit (typically thought of in a watershed context) varies depending on slope and soil type. Forestry is regarded as the best use of relatively steep land. On moderately sloping land, agroforestry in the form of tree crops for timber, fruit and nuts, as well as coconuts and bananas, offers the possibility of soil protection and financial returns in a moderately short period. Land quality is often higher, and erosion risk lower, on relatively flat land in lower

1 For example, in IPA the relevant price of a product for a grower would be the farm-gate price but in CBA, the relevant price for a community (country or region) would be the import parity price.

watersheds, favouring inclusion of food crops in horticultural systems. In developing an agroforestry training program in northern Fiji, SPC (2013) devised a planting system for training purposes where "indigenous tree species such as Dakua (*Agathis macrophylla*) and Vesi (*Intsia bijuga*) were planted on top of the slope, while trees of economic value, such as sandalwood were planted together with citrus and other fruit trees in the middle of the slope with root crops over the base of the slopes. … on flat land, crops such as taro, pigeon pea, okra, cowpea, water melon, eggplant and capsicum were planted."

Agroforestry sometimes involves distinct planting patterns, e.g. mixed-species agroforestry, alley cropping (sometimes following land contours) such as in wide-row rubber plantations, and taungya (a form of shifting cultivation in which villagers grow food crops and provide a labour force during establishment of government-owned tree plantations). Timber trees contribute shade, shelter from typhoons, organic matter or other benefits for other timber, fruit or nut tree species, and short-rotation and annual crops.

A very wide range of species are planted in agroforestry sites in Fiji and Vanuatu, but there appears to have been little financial evaluation of the particular mixtures of species adopted. Clarke and Thaman (2014) reported that "over 100 trees or tree-like species are found in the agroforestry systems of Namosi and Matainasau villages in Viti Levu in Fiji". These authors provided a long list of important agroforestry tree and tree-like species for the location. It would appear that apart from coconut plantations with pastures or intercropping, there are no particular agroforestry systems in terms of species, field layout and other features that dominate in Fiji and Vanuatu. However, a number of priority tree species have been identified, and these are the focus of the financial analyses currently being conducted in the ACIAR SRAs.

The likely costs and returns—and hence financial performance indicators—of selected tree species suitable for inclusion in smallholder agroforestry systems are being estimated, with particular focus on areas of suitable but underutilised land in Fiji and Vanuatu. For this purpose, lists of priority tree species in Fiji and Vanuatu are being identified from research in other ACIAR projects in these countries, country visits and literature reviews. These tree species include the food species breadfruit (*Artocarpus altilis*), tropical almond (*Terminalia catappa*) and cacao (*Theobroma cacao*), and the timber species whitewood (*Endospermum medullosum*), sandalwood (*Santalum yasi* in Fiji and *Santalum austrocaledonicum* in Vanuatu), vesi (*Intsia bijuga*), flueggea (poulumi, *Flueggea flexosa*) and Pacific kauri (*Agathis macrophylla*).

IPA is also the appropriate evaluation method for short or indeterminate rotation species suitable for agroforestry intercropping (e.g. banana, papaya, vanilla, pineapple, kava, pongamia) and for annuals that are likely to be grown on the same land for a number of years (e.g. vegetable and root crops). Costs and returns of these species are sometimes evaluated using a gross margins analysis (GMA) framework. For example, a comprehensive collection of GMAs for food crops (including some tree species) in the Fiji sugarcane belt has been compiled by Leslie (2013). However, this analysis does not take into consideration all capital outlays and no discounting is applied, hence some reworking is needed for integrating the GMA models into financial models of agroforestry species. A necessary first step in the financial analysis of mixed species agroforestry (MSA) systems is to develop financial models for individual tree and crop species.

FINANCIAL PERFORMANCE CRITERIA FOR INVESTMENT PROJECTS

Financial modelling involves a systematic process: clearly defining the project to be evaluated, deciding on a project life or planning horizon for the evaluation, determining the appropriate discount rate, determining the relevant cash flow variables and estimating the annual cash flows (capital outlays, operating costs, project revenue), calculating project performance criteria, and usually conducting some form of sensitivity analysis.

Once promising novel tree species have been identified, IPA can be applied to determine whether growing these species is justified on financial grounds from the viewpoint of the investor (i.e. community landowner group or individual farmer). Growing the species, as an investment project, is evaluated by discounted cash flow (DCF) analysis, which takes account of the timing of expenditure and revenue throughout the chosen planning horizon. While various computing platforms can be used for bioeconomic modelling, and in particular financial analysis, Microsoft Excel is widely known, relatively simple to use and has considerable flexibility. The discussion here adopts an Excel spreadsheet format. A more in-depth discussion of the theory and method of financial analysis—and capital budgeting in general—can be found in Dayanandra et al. (2002).

The NPV and IRR

The most widely used DCF performance criteria for evaluation of an investment project are the net present value (NPV) and the internal rate of return (IRR). Other useful criteria include the peak deficit (the greatest amount by which the investor goes 'into the red') and the payback period (number of years before the investor is, and remains, 'in the black') for the project. The NPV is defined as follows:

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

where $C_t = B_t - CO_t - OC_t$

Here C_t represents the incremental net cash flow of the project in year t, defined as the annual project 'benefits' B_t (essentially revenue but this can also include costs avoided) less the capital outlays CO_t less the operating costs OC_t. The term n is the assumed project life, r represents the discount rate (essentially the cost of capital as an annual percentage) and t is the year index. For example, if r were 8% then the cash flow at the end of the first year C_t would be divided by $(1 + 0.8)^1$ or equivalently discounted by being multiplied by the reciprocal 0.9259. The further into the future the cash flows are, the smaller the multiplier of C_t, and hence the greater the discounting or reduction of the cash flow for the year. This may be viewed as allowing for time preference for money; it is assumed that people will value a dollar received today more highly than an equally certain dollar received at some future date. The NPV is the predicted increase in wealth of the investor from implementing the project, measured in today's dollars or other currency unit.

The internal rate of return is the discount rate (value of r) for which the NPV is exactly zero or the project just pays its way. This provides a percentage rate of return on the investment or indicator of the highest cost of capital that the project could support. Some problems can arise in calculating the IRR (e.g. it may not exist or there may be multiple discount rates for which the NPV is zero, depending on the pattern of annual cash flows) or it may be meaninglessly high if the project has small capital outlays relative to the annual costs and revenues.

Example 1. Simple illustration of calculating financial performance criteria

Suppose a project requires an immediate capital outlay of $25,000, and generates annual revenues of $15,000 and has annual costs of $4,000 over its three-year life. The discount rate is 8%. It may be assumed that capital outlays occur at the beginning of the year, while project revenues and operating costs occur at the end of each year. The calculation of the NPV is set out below, yielding a figure (estimated increase in investor's wealth in today's dollars) of $3,348.

Year	0	1	2	3
Capital outlay ($)	25,000			
Project revenue ($)		15,000	15,000	15,000
Operating costs ($)		4,000	4,000	4,000
Net cash flow ($)	−25,000	11,000	11,000	11,000
Discount factor	1	0.9259	0.8573	0.7938
Present value of net cash flow ($)	−25,000.00	10,185	9,430	8,732
Net present value ($)	3,348.07			

In this table, the year numbers run from zero (now) to three (the end of the third year). The net cash flow row is the difference between the project revenue row and the sum of the capital and operating cost rows. Thus, the net cash flows for years one to three are all \$15,000 – \$4,000. In the case of year zero, because there is no revenue or operating cost, the net cash flow is the capital outlay subtracted from zero (hence the negative sign). A row of discount factors is entered below the net cash flow row. The factor for year zero (now) is 1, meaning that the immediate capital outlays are not discounted. The discount factors $1/(1 + r)^t$ or 1.08^t increase progressively for the ends of years ($t = 1$, 2 and 3). The annual net cash flows are multiplied by the discount factors to obtain their present values, which are summed to obtain the NPV.

To obtain the IRR or discount rate for which the project exactly breaks even (has an NPV of zero), we could simply calculate the NPV for a range of discount rates and make an interpolation. The NPV for four rates are as follows.

Discount rate (%)	4%	8%	12%	16%
NPV (\$)	5,526	3,348	1,420	–295

From inspection of this table, it is apparent that the IRR is between 12% and 16% and closer to the latter (probably about 15%). In the Excel spreadsheet there are NPV and IRR functions to automate the calculations.

Project balances and the peak deficit

One problem with forestry projects for timber production is that the payback period is usually the rotation length, that is, the investor becomes increasingly 'out of pocket' right up to the harvest age of the trees. Agroforestry systems are designed to generate revenue early in the project life from the inclusion of short-rotation tree species, fruit and nut trees, and food or other crops. Because of this pattern of cash flows to ensure survival income throughout the 'project life', the traditional DCF analysis criteria do not really address the financial viability aspect of agroforestry projects. Rather, it is necessary to examine the pattern of cash flows over time. The project balance at the end of each year may be thought of loosely as the NPV which would be obtained if the project was suddenly terminated at that time. This is not exactly correct because, for example, assets are usually acquired when projects commence, which have some residual values, and these could be liquidated early. The peak deficit is the largest negative annual project balance. The payback period is the first year in which the project balances become—and subsequently remain—positive. To reiterate, three widely used financial performance criteria—NPV, IRR and payback period—are derived with reference to discounted annual net cash flows, i.e. taking account of the time preference for money or cost of capital.

Returns to capital versus returns to other factors of production

The broad resource groups used in agriculture and forestry enterprises are land, labour and capital. Traditionally, financial analysis assumes that capital is the most limiting resource and performance criteria, including NPV and IRR, are designed to focus on returns to this resource. However, the opportunity for smallholders to improve their livelihood is often constrained by limited supplies of their own labour (including family members) and limited land. In developing countries, where a relatively low level of technology is frequently adopted in farming, there is typically a high level of labour intensity. The major resource input in agroforestry projects is household and hired labour. Rather than focusing only on wages as an operating cost, the analysis also needs to examine returns to labour as a project benefit. A method for doing so is presented later in this paper.

APPLYING INVESTMENT PROJECT ANALYSIS TO FORESTRY AND AGROFORESTRY SYSTEMS

A proposed plantation development may be defined as an investment project, to be subject to DCF analysis. A first step is to clearly define the components of the project, the relevant cash flow items and the timing of expenditure and income.

Identification of the 'without-project' and 'with-project' cases

For financial analysis, a forestry or agroforestry project must be defined in terms of the 'without-project' and 'with-project' cases. It is the difference between the predicted cash flow streams for these two cases—the incremental cash flows—that is relevant for the analysis. The without-project case can be described in terms of the current land use which will be displaced but with allowance for predicted changes in land use over time without intervention. This would include, for example, the expected harvests from continuing to grow the current crop, perhaps with predicted declining yields due to land degradation or declining product prices due to market factors. For simplicity, the current land use and revenue generation is often assumed in the without-project case. The with-project case is the implementation of the forestry or agroforestry project with the capital outlays this requires and with the predicted new operating costs incurred and revenue generated.

Identifying relevant cash flow variables

Most project incremental expenditure and revenue items are relevant to financial analysis but some complexities arise. Interest payments on borrowed funds are excluded; these are simulated by discounting. Similarly sunk costs, i.e. money already spent in relation to the project before the evaluation begins and not retrievable, are excluded. If the land had been cleared or other improvements made before the point in time when the decision was being made about whether to go ahead with tree planting, then the cost of clearing or other land improvements would be irrelevant to the analysis.

An important group of with-project costs are those which do not involve financial transactions, known as opportunity costs. If old coconut trees were removed, the income foregone from no longer being able to harvest coconuts would be included as a project cost. Forestry and agroforestry are typically labour-intensive activities, and if landholders do much of the work themselves, then a value (opportunity cost) should be placed on their time input. This could also be thought of as income foregone, e.g. due to no longer having the time to do off-farm work.

In situations where landholders pay income tax, an increase in amount of tax paid relative to that paid on their overall income in the absence of the project is a relevant cost item in the cash flow stream.

Determining the project life

The number of years for which the financial analysis is conducted is a matter of judgment. Because discounting leads to cash flows further into the future having declining impact on the NPV, usually not more than 30 years is a suitable project life. Obviously the number of years should include the time at which timber is harvested, and in the tropics the harvest age is not usually more than 30 years and is sometimes less than 10 years. For agroforestry systems, the project life will generally be the rotation period of the tree species with the longest harvest age or production life.

Determining the discount rate

The discount rate adopted is typically the weighted average cost of capital across sources of borrowed funds and the opportunity cost of the landholder's own savings. A premium may be added to the discount rate if the project has high risk, i.e. the returns are relatively unpredictable. The rate adopted is a forecast for the cost of capital throughout the life of the project. The concept of a discount rate is generally poorly understood by researchers, and the rate adopted is often inappropriate. One practice is to determine the rates that have been used in the past when evaluating similar projects. This has two main flaws—previous researchers may not have understood the discount rate concept, and past rates may not be a good guide to future rates (an example being where there is a fall in loan interest rates due to a global financial crisis).

Constant versus current price analysis

Most often, input and output price levels applied at the present time are held fixed throughout the project life—known as constant price analysis. An alternative would be to build an annual inflation component into input and output prices over the life of the project—called current price analysis. In current price analysis, it is necessary to adjust the discount rate in relation to market interest rates by removing the inflation rate. Current price analysis is more flexible in that different rates of change over time can be applied to different cash flow items, e.g. to labour, fuel, fertiliser and the stumpage price of logs. Notably, a constant price analysis is easier to perform, and differences in rates of price change between cash flow variables are usually difficult to predict. Further, rates of price change may be relatively similar across the board. Most frequently, a constant price analysis is conducted.

Developing a spreadsheet template

Once the data requirements are identified, it becomes possible to commence setting up a financial model, usually in the form of a Microsoft Excel spreadsheet although other software specifically designed for IPA is available. Development of a prototype spreadsheet will assist in more clearly identifying the specific parameters required. It is sometimes possible to draw on already existing spreadsheets (e.g. of timber plantations) though these will require modification and sometimes there is little to be saved in modelling time.

DEVELOPING A SPREADSHEET MODEL, DERIVING PERFORMANCE CRITERIA AND CARRYING OUT SENSITIVITY ANALYSIS

A convenient format for a forestry or agroforestry financial model consists of a number of components (separate blocks in a spreadsheet or separate sheets in an Excel workbook). It is usually convenient to list the values of all of the physical and financial parameters estimated for the analysis at the top of the spreadsheet so that the input data assumptions can be immediately inspected, and where necessary, adjustments made to their values. Below these, it is convenient to place the cash flow table, which contains formulae only, and in which the annual levels for capital outlays, operating costs and project revenue are computed for each year of project life. Typically, time in years is listed across the top of the cash flow table, with annual cost and revenue items across the rows. The sequence of annual net cash flows is obtained from the cash flow table and is used for calculating the financial performance criteria, namely NPV, IRR, project balances, peak deficit and payback period. Information about the stability of the performance estimates in relation to uncertainty is often placed next in the spreadsheet; this may include sensitivity analysis, breakeven analysis and scenario analysis. A further block of rows, which is useful if the spreadsheet is moderately complex, contains a list of key assumptions of the analysis.

The reason for separating the parameter list from the cash flow table is that this avoids having to include any 'magic numbers' in the latter. If any form of stability analysis is to be conducted, changes can be made in the parameter list only and this will automatically result in changes in the annual cash flows.

In the stability analysis, changes are made to the levels of various physical and financial parameters (those which are expected to have the greatest impact on net cash flows or for which the greatest uncertainty exists) with parameter values varied individually or in groups. In sensitivity and scenario analysis, often pessimistic, best estimate and optimistic levels of parameters are assessed in terms of their impact on overall project financial performance (usually the NPV). Breakeven analysis is designed to find the parameter values for which the NPV is exactly zero.

EXAMPLE OF FINANCIAL ANALYSIS OF A FORESTRY INVESTMENT

A spreadsheet model has been developed to illustrate the financial analysis of a forestry project. This concerns the growing of the fast-growing Pacific island tree species *Flueggea flexuosa*, which is considered to produce high-quality fence posts on a 6–7-year rotation and poles after a few more years (Thomson 2006). This model has a number of simplifications,[2] but is well suited for illustrating the overall financial analysis in Microsoft Excel, including calculating performance criteria and conducting sensitivity analysis for a single tree species. A screenshot of the spreadsheet is provided below.

Example 2: Financial model for growing Flueggea flexuosa (poumuli) for fenceposts

The first block of spreadsheet cells (rows 3–11) lists the assumed parameter values. The cells contain

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Financial model for growing poumuli (*Flueggea flexuosa*) for fenceposts**														
2															
3	**Parameters**														
4	Area planted (ha)	0.5		Weedicide chemical required (cc/tree					5						
5	Harvest age (yrs)	7		Pruning labour, yrs 3&4 (hrs/seedling)					0.15						
6	Spacing within rows (m)	6		Plantation maint., yrs 5-7 (hrs/tree)					0.2						
7	Spacing between rows (m)	6		Wage rate ($/7 hr day)					15						
8	Number of seedlings required	138		Seedling cost ($/seedling)					1						
9	Land preparation labour (hrs/ha)	30		Weedicide cost ($/litre)					25						
10	Planting labour (hrs,seedling)	0.2		Stumpage value ($/tree)					20						
11	Weed spraying labour, yr 1&2 (hrs/seedling	0.3		Discount rate ($)					8%						
12															
13	**Annual cash flows**														
14	Year	0	1	2	3	4	5	6	7						
15	Capital outlays														
16	Land preparation cost ($)	32													
17	Seedling cost ($)	138													
18	Planting cost ($)	59													
19	Total capital outlay ($)	229													
20															
21	Operating costs ($)														
22	Weed spraying labour ($)		89	89											
23	Weedicide cost ($)		17	17											
24	Pruning labour cost ($)				44	44					**Sensitivity analysis**				
25	Plantation maintenance labour ($)						59	59	59		Wage rate ($)/day		12	15	18
26	Total operating cost ($)		106	106	44	44						1124	1188	1124	1061
27															
28	Project revenue ($)										Weedicide cost ($/litre)		20	25	30
29	Post timber sales ($)								2760			1124	1131	1124	1118
30															
31	**Project performance criteria**										Stumpage price ($/tree)		16	20	24
32	Annul net cash flow ($)	-229	-106	-106	-44	-44	0	0	2760			1124	802	1124	1446
33	NPV ($)	1124													
34	IRR ($)	32%									**Breakeven analysis**				
35	Annual project balance ($)	-229	-327	-418	-453	-486	-486	-486	1124			Wage rate ($/day)			68.15
36	Payback period (year)	7										Weedicide cost ($/litre)			939
37	Annual labour requirement (days)	6	6	6	3	3	4	4	4			Stumpage price ($/tree)			6.04
38	NPV ($)/Labour use (days)	32													

2 The model is highly simplified in that it does not consider, for example, plantation thinning, expenditure on pest and disease control, infilling for seedlings that are killed or damaged when first planted, tree losses due to cyclones or any government subsidies or taxes.

mostly just numbers, but cell B8 contains the formula =INT(B4*10000/(B6*B7)), i.e. a calculation for the number of trees planted as the integer value of the plantation area in square metres divided by the product of tree spacing between and within rows.

The second block of cells (rows 13–28) contains the components of the annual cash flows. The capital outlays include the cost of land clearing and of purchasing and planting seedlings. The planting cost in cell B18 is obtained as =B8*B10*I7/7. Here B8 is the number of trees planted, B10 is the planting time per tree in hours, and I7/7 is the labour cost per hour in a 7-hour work day. The annual operating costs include labour costs for silviculture, including weed control (for which Roundup weedicide is purchased). Sale of standing trees is the only source of project revenue and is calculated as =B8*I10, i.e. number of trees planted multiplied by the stumpage price per tree.

The third block of cells (rows 31–38) reports the project performance criteria. The annual net cash flows (annual estimates of project revenue less capital outlays and operating costs) have been included in this section. The NPV is calculated as =B32+NPV(I11,C32:I32). Here the NPV financial function is used, the 'arguments' of which include the discount rate and then the annual net cash flows for each of years 1 to 7. Because the capital outlay in year 0 (the beginning of the first year of project life) is not discounted, it is included outside of the NPV function arguments. Next the IRR is calculated as =IRR(B32:I32), again using one of the Excel financial functions, which in this case performs the IRR estimation over all of the annual net cash flows including for year 0.

An important concern for landholders considering investment in forestry or agroforestry is the financial situation and labour demand in each year throughout the project life, not just the overall project performance indicators. The annual financial situation is depicted by the project balances, as derived in row 35. These represent the amount that the project owes the investor (i.e. the amount the farmer is out of pocket) at the end of each year. For example, the project balance for year 4 is =E35+F32/(1+$I11)^F14, i.e. the project balance at the end of the third year, plus the net cash flow for year 4 divided by (1 plus the discount rate) to the power 4. This project balance of $486 is in fact the peak deficit or greatest financial commitment required to undertake the project. The project balance in the harvest year (year 7) is the NPV, and because this is the first positive project balance, the project payback period is 7 years, i.e. the harvest year.

Row 37 summarises the number of days of labour that will be required by the project each year. Notably, the NPV is calculated after allowing for all costs of growing the plantation, the largest item of which is the labour cost. In the likely event that the farm family does all of the plantation work, all of this cost can also be regarded as family income.

Intuitively, the NPV divided by the total amount of labour required by the project will give some indication of the return to labour of the project. In fact, this is illusory and the ratio (here 32 in dollar units) is really only an inverse measure of labour intensity in the project. To take an extreme situation, if nearly all the project work could be automated (or handed over to a contractor) such that the farmer had to spend only one hour of their time working on the project, then the ratio would be the full NPV of $1,124. All this figure would really convey is that the labour intensity is very low. A much more meaningful indicator of labour value is derived in the breakeven analysis.

Sensitivity analysis is conducted in which the wage rate, weedicide price and stumpage price (price received for standing trees at the end of year 7) are each varied by 20% above and below the best estimate. An increase in wage rate and in weedicide cost reduces the NPV, while an increase in stumpage price increases the NPV. The sensitivity analysis has been conducted using the Data Table option in What-if-Analysis, found under the Data menu of Excel. On selecting the Table function, a pop-up menu will appear to guide further steps. In the screenshot in Example 2, three one-way tables have been stacked, with the range of parameter values across the top of each and a cell reference to the NPV on the lower left.

As seen in the sensitivity analysis table, the wage rate and weedicide cost have very little effect on NPV. However, NPV is highly sensitive to stumpage price. Notably, we can infer that NPV is also highly sensitive to number of trees sold because the revenue is the product of quantity sold multiplied by price per unit.

To perform breakeven analysis, Goal Seek is selected in the What-if-Analysis submenu. In the pop-up menu which appears, the performance criterion (usually NPV) is selected in the *Set cell* field and a value of zero is assigned in the *To value* field. The parameter for which a breakeven value is sought is selected in the *By changing cell* field. The breakeven level for wage rate in the *Flueggea flexuosa* spreadsheet indicates that the wage rate could increase to over $68 a day before the NPV became negative (i.e. the plantation project became financially non-viable). This is a useful indicator of labour value in the project. It is consistent with the concept adopted by Cacho et al. (2008, p. 73) who noted in their agroforestry study that "return to labour was calculated as the wage rate that makes the NPV = 0, so it provides a measure of how attractive the activity is relative to alternative employment activities for the farm family".

The return to labour from the project would of course have to be compared against foregone wages if the farmer had to give up other employment to undertake plantation work, but the difference in daily earning rates could be large. Because so little weedicide is used, a very high weedicide cost could be accommodated. The project would still be financially viable if the stumpage price fell to around $6 a tree, all other parameters remaining constant.

A note on currency units and exchange rates

One of the decisions required in financial modelling for the SRAs concerns which country's currency units to use. The currency unit could be for example the US dollar (an international standard), the Australian dollar (the most convenient currency for an Australian researcher to use), the Fiji dollar or the Vanuatu vatu. The exchange rates relative to the Australian dollar as at 11 December 2014 were approximately A$1 = US$ 0.83, F$ 1.65, and Vanuatu vatu 86.43. The initial decision was to use the Australian dollar but this has limitations if the financial estimates are to be used for policy purposes in Fiji or Vanuatu. The final decision was to use the currency unit of the country for which each of the agroforestry system financial models was most suited or relevant. Notably, it would be a relatively simple task to include a 'switch' facility for changing the currency unit to that of the country for which the agroforestry system model is being considered, which would increase the flexibility of the financial models.

DATA REQUIREMENTS FOR FINANCIAL ANALYSIS OF FORESTRY AND AGROFORESTRY SYSTEMS

Initial design consideration

Once a planting site is chosen, decisions must be made about the size of the area to be planted, the species to be planted and the spacing between and within rows (and associated planting density in stems per hectare (SPH)). While intimate species mixtures are occasionally used, intercropping and discrete species blocks are more common. Intercropping is often short term because as trees grow towards canopy closure, the sunlight available to intercrops declines. The source of seedlings or other propagules must also be decided, i.e. purchased (perhaps with some discount or subsidy available) or produced by the landholder or community in their own nursery. A decision may be needed about the form of propagules because sometimes grafted seedlings, cuttings, wildlings or in the case of root crops, tubers or corms may be preferable.

Setting out the project activities

Physical and financial information about tree-growing activities in the without-project and with-project cases is required, for which a large number of parameters will need to be estimated. As a first step, it is necessary to identify the physical activities which will need to be undertaken in the project. A forestry project can involve an impressive number of physical and administrative activities, for example:

- obtaining planting permission;
- obtaining any equipment needed (e.g. hand tools, knapsack sprayer, buckets and crates, chainsaw); farmers will often already have much of the equipment needed;
- acquisition of planting materials (e.g. obtaining planting materials and transporting them to the planting site);
- land clearing or other site preparation;

- fencing to exclude grazing animals;
- planting, which may include hole digging and application of inorganic or organic fertiliser;
- staking and installing tree guards;
- infilling, where outplanted seedlings are damaged or destroyed, e.g. by grazing animals or cyclones;
- fertilising;
- weed control, e.g. ring weeding;
- pest and disease control;
- pruning (including shaping fruit trees);
- thinning (and perhaps composting thinnings or preparing them for fuelwood);
- harvesting of timber, fruit, nuts;
- post-harvest processing;
- transporting and selling final products;
- destumping or other site rehabilitation.

Based on the project activities, lists of physical and financial parameters can be drawn up, levels (quantities or prices) of which go into a spreadsheet. In a sense, these are all forecasts of future quantities (physical units and time requirements) and prices of inputs and outputs.

Physical parameters

These are mainly labour times (work rates) for various activities, quantities of inputs (fertiliser, pesticide) and yields of harvested products (timber, nuts, fruit). The area planted (ha), tree spacing (m) and hence planting density (SPH) are also required.

Price or cost estimates

There can be a number of cost or price estimates associated with forestry and agroforestry activities, for example:

- costs of purchasing hand tools, fencing materials, chainsaw;
- maintenance cost of plants, equipment and tools;
- cost of containers, e.g. crates, buckets, bags;
- land preparation cost when contractors are used;
- cost per unit of seedlings or other propagules;
- fertiliser, herbicide, pesticide and fungicide cost;
- wage rate or opportunity cost of any hired labour;
- harvesting cost of contractors, where relevant;
- on-farm product grading and other processing costs;
- interest rates and inflation rate (to calculate weighted average cost of capital (WACC));
- taxation rate (if the smallholders have to pay tax) and value of any subsidies available.

MAJOR CHALLENGES FOR FINANCIAL ANALYSIS OF GROWING NOVEL TREE SPECIES

A substantial amount of information on relationships and parameter values is required in developing financial models for the production of novel tree species. By definition, there is little or no history of the growing of these species commercially so there is considerable uncertainty about the reliability of parameter estimates. From financial modelling experience of these species undertaken in the SRAs to date, some particular modelling challenges have arisen, the more apparent of which are elaborated here.

Determining the land opportunity cost

Suppose an area of land is already totally or partially cleared and new timber or fruit trees are to be planted. If the land is currently idle then there will be no opportunity cost (i.e. annual revenue foregone) from clearing the land. If the land carried some coconut palms which are still bearing fruit (though perhaps with low yield) or some abandoned sugarcane which is being grazed by cattle, then there will be the loss of an annual income stream. In the financial analysis, this opportunity cost relative to the without-project case can be treated as either a project operating cost or a negative project annual revenue, the latter probably being the more appropriate. In practice, the annual foregone income can be time consuming and difficult to estimate, and in any case is likely to be small, so a subjective ballpark estimate may be acceptable.

Costing planting materials

Communities generally have the capacity to produce their own planting materials. They can set up nurseries quickly if there is an incentive to do so and if they have an accessible water supply. The nurseries can be quite primitive and inexpensive, for example constructed of bush poles and with palm fronds for shade. However, a few qualifications need to be made. There may be adverse selection of seed, e.g. obtaining seed from low trees for convenience in picking. Special processes may be required, such as grafting of rootstock, for which skills need to be acquired. Potted seedlings grown on bare earth may develop deformed root systems or roots may be broken when the pots are lifted. Sun-hardening of planting stock is usually needed before out-planting and this is sometimes overlooked. These problems can be overcome with some assistance measures, including provision of high-quality germplasm (typically seeds) and provision of technical training. Seedlings of some tree species—particularly native species that do not seed regularly—can be difficult to purchase, although often wildlings can be collected and grown in nurseries until ready for out-planting. From a financial analysis perspective, production of seedlings and collection of wildlings become project activities, and sale of seedlings to other farmers, or even to government for other projects, could take place, becoming an additional project revenue item. Overall, the cost of planting material and delivery to the planting site can vary greatly between landholders. However, this cost can be low relative to labour costs and the simplest approach may be to assume the seedling cost from local nurseries.

Estimating work rates

Labour cost is usually a major component of the capital outlay and operating cost of smallholder timber and other tree crop projects. It is therefore important to have reasonably reliable estimates of the time taken (per tree or per unit of products) for silvicultural activities (e.g. planting, weed control, thinning and pruning), harvesting and post-harvest processing. For the SRAs, some consensus estimates of time requirements have been obtained from literature review and by questioning foresters. However, there can be large variations in time requirements. As an example, the time requirement for tree planting will depend on soil type, size of the seedling root system and hence size of hole required, whether fertiliser is applied at planting time and whether existing root systems have to be broken up, as may be necessary when planting under coconut palms. In general, considerably more time is warranted in planting fruit and nut trees compared to planting timber trees.

Estimating the labour cost and working day length

Because labour for planting, establishment and management is a major component of agroforestry projects, the cost of labour is usually an important parameter in sensitivity analysis of financial models. When labour is hired, wages and any other costs (e.g. transport, food and accommodation) are costed. However, frequently household labour is used, for which an opportunity cost has to be imputed. If outside employment is foregone to work on the project, then the net earnings (after deducting travel costs and income tax payments on wages but adding the value of food or other items provided by the employer) can be treated as an opportunity cost. If leisure time is foregone, the costing becomes more difficult and a non-market valuation method may be required. Multiple households working together and exchanging labour can be another complexity. For simplicity, the minimum adult award wage is sometimes taken as the opportunity cost of own labour. A further complexity is that where household members in traditional communities are providing labour input to forestry or agroforestry projects, the number of hours per day may need to be adjusted for workers' social responsibilities in their communities (as found in a consultancy project in Mindanao), and the concept of a culturally appropriate working day (as developed by Venn (2004) in a forestry project in Cape York, Australia) may need to be adopted.

Estimating plant protection and crop nutrition costs

Smallholder crop protection costs can arise for fencing to exclude grazing animals and for windbreaks, pest and disease control, and protection of products from theft. In practice, grazing animals are often tethered and smallholders frequently use traditional pest and disease measures or tolerate pest and disease damage rather than spending money on control measures. Similarly, organic fertiliser may be used if available, or little or no fertiliser may be used. Thus, there can be a wide gap between recommended practice and associated costs, and actual practice, sometimes with much higher product loss. It can be difficult to determine the level of crop protection and nutrition when carrying out financial modelling. The farmers' behaviour could be rational or due to a lack of funds or lack of information; the extension advice could be well judged or conservative or politically correct. A special concern arises with regard to protection from wildfire (not discussed in this paper).

Deriving yield estimates or yield curves

Tree performance is obviously highly variable, depending on variety, management, site conditions, season and other factors. Typically, reasonably reliable estimates can be made of timber volume and yields of fruit or nuts for recognised commercial species. Greater difficulty arises for novel species, for which there may be little documented yield evidence. Even with commercial species, the yield profile (i.e. the age at which the first commercial harvest is made and how yield changes over time) may be difficult to estimate. Various mathematical equation forms are used for estimating yield curves. Timber volume is usually assumed to increase up to an asymptote and can be estimated by the mean annual increment (MAI, in say m^3/ha). In the case of fruit and nut trees, an age of first commercial yield and an age of steady yield are sometimes reported, although in reality there will be declining yields for ageing trees and yield curve fitting becomes more difficult. Once the yield curve form for timber or other products is specified, and some data points obtained, the non-linear programming facility in Microsoft Excel can be used to estimate parameters to the curve through minimisation of the sum of squares of lack of fit of the estimated curve to the data observations.

Estimating farm-gate product prices

Retail prices can be observed in markets and photographs of these have been obtained through fieldwork in the SRAs. In contrast, the amount actually received by the farmer (the relevant figure for financial analysis) is often particularly difficult to estimate. Farmers who sell produce in local markets by boot sale (e.g. literally from a car boot or off the back of a utility) incur some minor vehicle costs and perhaps market fees but can be expected to receive most of the market price. Farmers who sell produce at their farm to an assembler who perhaps sells on to a merchant may receive less than 50% of the final market price and sometimes only about 20% of the market price. For a given product, the supply and value chain differs between product types and between locations.

Determining post-harvest processing needs and costs

The extent of post-harvest processing can vary greatly between communities and individual landholders, and interesting examples exist in relation to sandalwood, cocoa and canarium nuts. The valuable product of sandalwood is the heartwood of both the roots and the trunk and the highest value use is carving timber. The grower could simply sell the trees or could remove the bark and sapwood and dry the timber before sale. Cocoa could be sold as pods, wet beans with pulp, dry beans or products with further value-adding (particularly with community processing). Canarium nuts could be sold in husk, in shell or as dried kernels. In each case, identifying the level of post-harvest processing that growers are likely to perform (i.e. the extent of value-adding) is important because this can have a major effect on labour cost and on net revenue obtained.

Further challenges are now being experienced in modelling overall agroforestry systems with regard to species–site matching for tree and crop species, identifying compatible species mixtures, defining intercropping designs in terms of tree and crop spacing within and between rows, and modelling crop phase-out as trees grow and canopy closure is approached.

TESTING FORESTRY AND AGROFORESTRY FINANCIAL MODELS

A wide literature exists on the testing of bioeconomic models or farming systems models, and particular testing procedures and steps can be identified. In general, these consist of verification, validation and sensitivity analysis. Verification can be described as ensuring the model behaves as it is designed to behave, which in effect means debugging the programming (including spreadsheeting) code. In financial analysis using Excel, this equates to checking that all the formulae are correct. Sensitivity analysis may be thought of as having a dual role: checking which relationships and parameters are most important and hence require the most careful validation, and checking the robustness of the validated model.

The main concern in model testing is validation, i.e. checking that the model reliably mimics the real system that it has been designed to represent, or behaves like the real system will behave given the same environmental settings. In terms of a forestry plantation or woodlot, this can be viewed as determining whether tree growth and production of timber and other products, and costs and revenues, are reliable estimates of what would actually eventuate if the trees were planted. Various individual approaches, or a combination of several approaches, can be used for validation of the financial models. Potential approaches include the following.

1. Thorough literature review, including drawing on any physical and financial analyses reported in the literature.
2. Observations during field visits, interviews with key informants, and to the extent possible, surveys and case studies of current growers.
3. Data compilation by partner country participants.
4. Subjective validation by experts, both of the relationships and parameter estimates, and of the predicted levels of performance variables. The experts would be people with some familiarity with the system, i.e. with the tree species to be grown.
5. Presenting experts with performance data for the real system, and those predicted by the model, for the same resource inputs and management decisions, and asking them to distinguish between the real system and model outputs, and identifying the reasons for differences.

These steps can certainly improve financial models. However, experience suggests that applying validation procedures prior to real-life use of models can have limitations, and that confidence tends to be built up in models progressively as they are used and modified in a series of applications over time.

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4. Non-market values of agroforestry systems and implications for Pacific island agroforestry

Steve Harrison, Robert Harrison, Caroline Sullivan and Saiful Karim

Abstract

In general, financial analysis of forestry and agroforestry investments does not take into account the broader social, environmental, cultural, traditional and other benefits of these systems. Hence, this paper examines methods of estimating non-market values to provide policy support. Such values would have relevance with respect to carbon sequestration, sea-level rise, watershed protection, preserving mangrove areas and coastal fisheries, improving the supply of healthy food products to improve public health, and in general, a wide range of policy areas. Under social cost–benefit analysis, if the overall benefits—private, social and environmental—are found to exceed the costs (or the benefit-to-cost ratio is greater than 1.0), a project is considered to be justified on economic grounds. Because some important benefits are not reflected in market transactions, various methods have been developed to estimate values of non-market goods and services. Among the better known methods are: travel cost method (TCM) for valuing recreation benefits; contingent valuation method (CVM) for estimating consumer willingness to pay (WTP) for a wide package of benefits; and environmental choice modelling, which breaks WTP down into a number of components. The hedonic price method (HPM) is used to estimate values associated with market transactions, such as the values of attractive landscapes, low noise and proximity to public transport, with these estimated by their impact on property prices (i.e. as revealed rather than just stated preferences). In practice, the benefit transfer method (utilising values adopted from previous research rather than conducting new and costly evaluation efforts) is often used as a convenient expedient for non-market values. Many databases of environmental values have been developed, which allow values from a source site to be inferred for a target site. The importance of watershed protection or remediation is well recognised in Fiji and Vanuatu. Flooding is often associated with cyclones and can have serious impacts on tourism, cropping areas and watercourses. Various Pacific island tree species have wide-spreading root systems and are well suited for streambank and coastal land stabilisation. Revegetation of these areas can have considerable non-market benefits. Estimation of values of such benefits—say by CVM or benefit transfer—could be used to place dollar values on riparian and coastal tree plantings and to guide government policy as to whether such investment would be justified on broad socio-economic grounds.

INTRODUCTION

Many Pacific island agroforestry species are notable for the environmental and social benefits they generate. From an economics perspective, when no market transactions take place, no consumer preferences are revealed in the market place, and the impacts of activities (such as growing trees and other plant species) are referred to as positive or negative externalities or non-market benefits or costs. In this situation, policymakers could note the externalities, and subjectively rank these alongside the financial impacts of the activities, to guide their decisions. The early cost–benefit analyses (CBAs) of major government projects in the USA took this approach. However, from about the 1970s, substantial research was undertaken into developing and testing techniques for placing monetary values on non-market benefits and costs, generally using consumer survey approaches. Such non-market valuation is usually costly and time consuming, and a long list of potential biases in value estimates has been identified, although progressive refinements in valuation methodology has led to the ability of economists to generate reasonably credible value estimates.

Taking externalities of non-market benefits into account is in effect moving from private investment project evaluation to social CBA. Nowadays, both subjective importance rating and non-market valuation approaches are used in CBA studies to support policy analysis. The choice of approach depends to some extent on the preferences of the policymakers and the magnitude of proposed investments. Large investments are more likely to justify a detailed social CBA. In this context, the term 'social' refers to all non-market benefits rather than to 'values of social impacts' and the valuation methodology differs considerably from financial analysis. Transfer payments (taxes and subsidies) are excluded from the analysis because they do not represent any gain or loss to overall society. Shadow prices (import and export parity prices) are preferable to local market prices, the discount rate is reduced to that applying to the public sector, and other changes are needed.

Non-market benefits, non-timber forest products, and ecosystem services

In this paper, ecosystem services which are not traded or compensated are included as non-market benefits. Examples include local biodiversity protection (at genetic, species, ecosystem and landscape levels) and local climate amelioration. Some forms of ecosystem services attract payments to the providers, examples being payment for environmental services (PES; e.g. Lipper et al. 2009), ecological services (Secretariat of the Convention on Biological Diversity 2015) or payments for watershed services (PWS; e.g. Cohen 2008). Various examples can be found in the literature where communities receive payments for protecting or establishing vegetation in watersheds. When actual payments are made, these benefits cease to be classified as non-market benefits.

Non-timber forest products (e.g. fruit, nuts, fuelwood and organic fertiliser) when traded are regarded as market goods. But even when they are used by the producer's household, they can generally be treated as market goods, though valuation is more difficult. Their value could be estimated as the returns foregone from not selling the goods, or as the cost to the household if they had to be purchased rather than produced.

A more complex case concerns the value of carbon sequestration. In general, markets trading in carbon credits (more formally known as Certified Emission Reductions or CERs) have not commenced in Pacific island countries (PICs). The benefit of carbon sequestration from forestry and agroforestry in PICs is a global benefit rather than a local benefit. Carbon emissions averted in Fiji and Vanuatu would make a very small contribution to the overall atmospheric carbon in these countries (being diluted globally) or to adverse impacts such as rise in sea level. However, carbon sequestration is a national responsibility, and one which PICs take seriously, given their high vulnerability to the impacts of climate change including sea-level rise. This is reflected in the 'Pacific islands regional policy framework for REDD+' (Weaver 2012). In this paper, carbon sequestration is treated as a non-market benefit because PICs are now recording their carbon balances. Trading in CERs is likely to commence soon, and it appears to be standard practice nowadays to list these in forestry and agroforestry project evaluations. In the CBA context, the value placed on carbon sequestration by forestry and agroforestry can be viewed as the cost of the cheapest domestic alternative method of sequestering carbon.

Benefits of individual species vs benefits of mixed-species systems

Some non-market benefit types, and notably landscape amenity, can be expected to be higher for a given area for mixed-species plantings than for monocultures. To some people, monoculture forests are dark and depressing areas relative to pasture and, for example, views of cattle grazing. Mixed-species plantings more closely mimic natural forest systems. It has also been argued that mixed-species plantings can sequester more carbon per hectare than single-species plantations, from greater utilisation of the planting site. Agroforestry systems, including food crops, are likely to make a greater contribution to public health than timber monocultures. Silvopastoral systems, such as cattle under coconuts, can provide an important non-market benefit of fire prevention or retardation. In principle, it would be possible to estimate the increase in environmental values of multi-species agroforestry relative to monoculture forestry, for a given site.

AN OVERVIEW OF ENVIRONMENTAL AND SOCIAL VALUES AND EVALUATION METHODS

Various categories of non-market values have been identified, three broad groups in total economic value (TEV) typically being recognised—use value, option value, and bequest and existence value—as set out in in Figure 1. Values are viewed in terms of willingness to pay (WTP) for an environmental or social asset or service, and willingness to accept compensation for loss of an environmental or social asset or service. A number of methods have been developed for non-market valuation. Probably the least controversial are valuation methods for recreation sites and asset characteristics. The former are measured using the travel cost method (TCM), in which a demand function is estimated by a survey of what costs visitors have incurred to make a trip to a site. The latter are estimated through regression analysis using the hedonic price method (HPM). An example is valuing the views, access to public transport and other features of residential properties, where say attractive views are regarded as a yes/no condition, included as a dummy or 0-1 regressor in the list of explanatory variables for the overall property value.

TCM and HPM are known as revealed preference methods because they make estimations on the basis of what people have actually paid for a recreation site visit or for an asset. However, both methods estimate only a subset of values. Two commonly used methods to estimate total economic value of a specific asset or service are the contingent valuation method (CVM) and environmental choice modelling (CM). In CVM surveys, respondents are asked to value an entire bundle of benefits (e.g. a forest area) in terms of what they would be willing to pay to have it preserved or what compensation they would need to receive to agree to the asset being given up. In CM, a number of trade-off alternatives are presented, so that values can be estimated for particular characteristics of an environmental asset. Both approaches require surveys of the affected community, which may be entire countries, and usually require large samples. These and other stated preference methods—described in detail in Louviere et al. (2000)—are subject to various sources of bias, a simple example being that respondents may overstate values to influence policy towards protection of an environmental asset.

Various other non-market valuation methods have been developed, some examples being estimation of preventative expenditure (against environmental

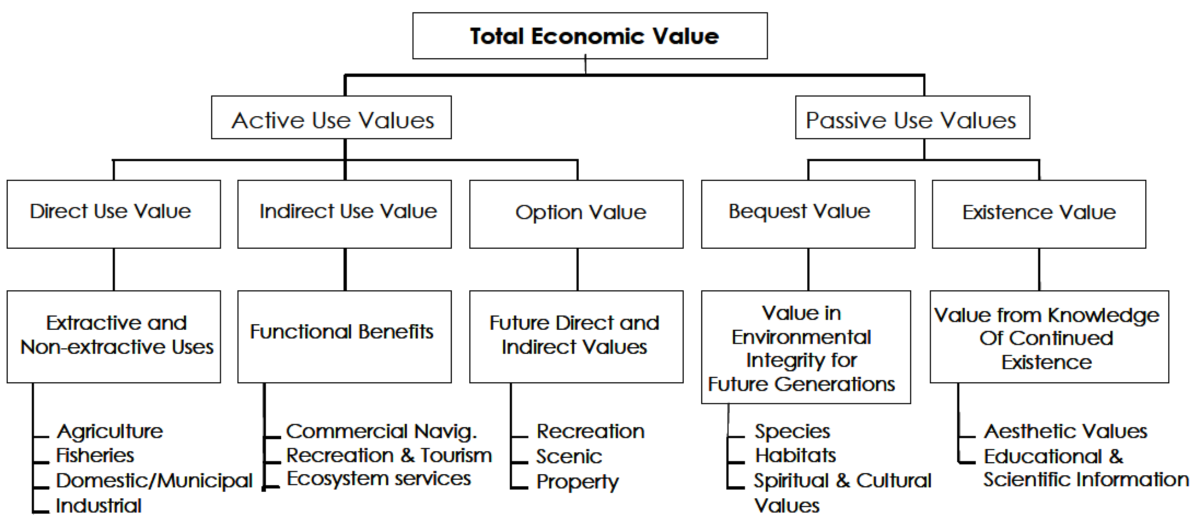
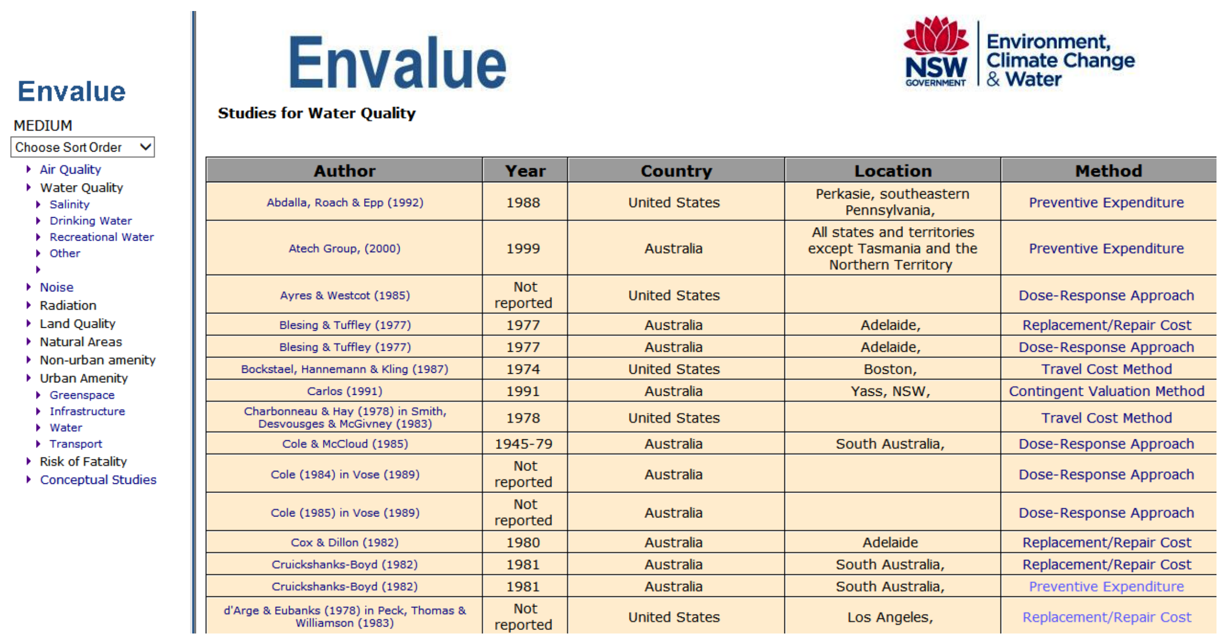


Figure 1. Components of total economic value. Source: Waikato River Authority (nd).

damage), dose-response approach, and replacement or repair cost. Given the high cost of any original data collection and estimation effort, a perhaps predictable development was the creation of databases of environmental values. A pioneer in this area was the now New South Wales Department of Environment, Climate Change and Water, which developed the Envalue database. According to the NSW Government (nd), "the ENVALUE environmental valuation database, developed by the NSW EPA and first released in 1995, is a systematic collection of environmental valuation studies presented in an on-line database. It is expected that the ENVALUE database will assist decision makers in government and industry as well as academics, consultants and environmental groups, to incorporate environmental values into cost–benefit analyses, environmental impact statements, project appraisals and overall valuation of changes in environmental quality."

Figure 2 provides part of a screen image from the ENVALUE database, where the medium (what is to be valued) of water quality has been selected. It is notable in this example that the sources of the information are only from Australia and the USA, have been derived by a number of methods (not all of which estimate total economic value), and are not recent, the database being last updated in 2006. The valuation summaries for individual studies can be opened and read, and reported per capita value estimates can be inflated to current prices. However, it is obvious that making inferences from a source or study site where the estimates were obtained to a target or policy site for which value estimates are needed, perhaps in another country, are at best coarse approximations. The target community may have a population with quite different incomes, education, priorities and attitudes to the environment. At the same time, it is noted that a great deal of effort has been devoted in recent years to developing improved databases of environmental values.

A more recently developed database is the Greek Environmental Value Database (GEVAD), which draws on studies from 49 countries for 167 specific environmental goods, using 38 valuation methods (Laboratory of Mining and Environmental Technology, and National Technical University of Athens 2011). The GEVAD website also provides references to environmental databases in other countries, including Australia, New Zealand and Sweden. It is noted on the website that "In recent years, legislative actions on environmental issues have dramatically increased all over the world, as



Envalue

MEDIUM

Choose Sort Order

- Air Quality
- Water Quality
  - Salinity
  - Drinking Water
  - Recreational Water
  - Other
- Noise
- Radiation
- Land Quality
- Natural Areas
- Non-urban amenity
- Urban Amenity
  - Greenspace
  - Infrastructure
  - Water
  - Transport
- Risk of Fatality
- Conceptual Studies

Envalue

Environment, Climate Change & Water

NSW GOVERNMENT

Studies for Water Quality

Author	Year	Country	Location	Method
Abdalla, Roach & Epp (1992)	1988	United States	Perkasie, southeastern Pennsylvania,	Preventive Expenditure
Atech Group, (2000)	1999	Australia	All states and territories except Tasmania and the Northern Territory	Preventive Expenditure
Ayres & Westcot (1985)	Not reported	United States		Dose-Response Approach
Blesing & Tuffley (1977)	1977	Australia	Adelaide,	Replacement/Repair Cost
Blesing & Tuffley (1977)	1977	Australia	Adelaide,	Dose-Response Approach
Bockstael, Hannemann & Kling (1987)	1974	United States	Boston,	Travel Cost Method
Carlos (1991)	1991	Australia	Yass, NSW,	Contingent Valuation Method
Charbonneau & Hay (1978) in Smith, Desvousges & McGivney (1983)	1978	United States		Travel Cost Method
Cole & McCloud (1985)	1945-79	Australia	South Australia,	Dose-Response Approach
Cole (1984) in Vose (1989)	Not reported	Australia		Dose-Response Approach
Cole (1985) in Vose (1989)	Not reported	Australia		Dose-Response Approach
Cox & Dillon (1982)	1980	Australia	Adelaide	Replacement/Repair Cost
Cruickshanks-Boyd (1982)	1981	Australia	South Australia,	Replacement/Repair Cost
Cruickshanks-Boyd (1982)	1981	Australia	South Australia,	Preventive Expenditure
d'Arge & Eubanks (1978) in Peck, Thomas & Williamson (1983)	Not reported	United States	Los Angeles,	Replacement/Repair Cost

Figure 2. Partial screenshot of the Envalue database. Source: NSW Government (nd).

a public demand for the protection, preservation and restoration of the environment. The latter stands especially true for EU, considering that in the 90s more than 300 legislative acts (Directives, Regulations, Decisions etc.) were introduced aiming at preventing, avoiding and restoring environmental damages. Within this new framework of actions and legislations, there is a growing effort to incorporate monetary values for environmental impacts in order to assess the costs and benefits of environmental policies."

A particularly useful overview of databases of environmental values has been provided by Van Landeghem (nd). It is noted that the Environmental Valuation Reference Inventory (EVRI) of Environment Canada has data from more than 1,900 studies and the Review of Externality Database of the European Commission more than 1,200 studies. Below is a list of various environmental value databases and related websites. Access to some of these is free, while a fee is charged for use of others.

- EVRI—http://www.evri.ca
- Envalue—http://www.environment.nsw.gov.au/envalue/
- Ecosystem Services Database (ESD)—http://esd.uvm.edu/
- Review of Externality Database (RED)—http://www.red-externalities.net/
- New Zealand Non Market Valuation Database—http://oldlearn.lincoln.ac.nz/markval/
- ValuebaseSwe—http://www.beijer.kva.se/valuebase.htm
- Beneficial Use Values Database—http://buvd.ucdavis.edu/buvd/index.htm
- EconPapers—http://econpapers.repec.org/
- Biodiversity Economics—http://www.biodiversityeconomics.org/
- Environmental & Cost Benefit Analysis News—http://envirovaluation.org/

CATEGORIES OF ENVIRONMENTAL AND SOCIAL VALUES OF PACIFIC ISLAND FORESTRY AND AGROFORESTRY

From a literature review, a long list of reported benefits of growing Pacific island tree species can be identified. Elevitch and Wilkinson (2000) listed as benefits the broad categories of aesthetics, legacy, cultural values, watershed, habitat, erosion control and soil improvement, and placed hypothetical 'perceived values' of individuals on these benefits.

Thaman et al. (2000, pp. 40–44) provided a highly detailed product and use table with importance ratings of various categories of market and non-market benefits for a large number of Pacific island species across all Pacific islands. This source provides, for example, itemised lists for: timber, food and other marketable products; fencing materials; medicinal, ceremonial and religious products; wildlife benefits; crop, water and land protection; special materials (e.g. carving timber, canoe constrution materials, fishing equipment, rope); and oils for illumination and lubricants.

Harrison (2000) examined landscape amenity values in relation to farm forestry, noting that planted forest enhances visitor experience when designed to mimic native forests, but is sometimes viewed negatively in areas of previously attractive open non-treed landscape.

Alavalapati et al. (2004, p. 4) noted that "methodologies are … available for assessing a variety of environmental advantages and challenges (e.g. carbon sequestration, biodiversity and soil erosion) for which there are no established markets. While some methodologies are appropriate for assessing AFS [agroforestry systems] at the individual farm or household level, others are applicable at regional and national scales."

Pannell (2009) noted a number of benefits of agroforestry, including preservation of threatened species, flood mitigation, carbon sequestration and control of off-site watertables (waterlogging) and dryland salinity.

Smith (2010) identified a number of environmental benefits of agroforestry (relating to soil, water, biodiversity and climate change) and social benefits (product diversification, rural skills and employment, reduced reliance on fossil fuels, aesthetics, culture and recreation). Smith also reported productivity benefits, including reducing inputs.

SPC and GIZ (2014) noted the effect of urban trees on the local environment, commenting that "trees provide green infrastructure—shade, evaporative cooling, and rainwater interception, storage and infiltration—in cities [and] tropical forests influence precipitation and can have a cooling effect on a region through increased evaporation and cloud cover." This is consistent with the comments of Doick and Hutchings (2013, p. 2) in relation to urban trees and green infrastructure, who noted that during a UK heatwave night temperatures were 9°C higher in London than in surrounding areas. Similarly, it could be expected that reforestation or agroforestation of the 'brown hills' of western Viti Levu would reduce regional temperature.

Particular categories of non-market benefits

Based on the above review of non-market benefits and other literature sources, especially for traditional tree species in Pacific islands, a list environmental and social benefits of agroforestry has been developed (Table 1). In addition, a wide variety of non-timber forest products which can be categorised as market benefits can be identified.

ENVIRONMENTAL AND SOCIAL VALUES OF PARTICULAR PACIFIC ISLAND TREE SPECIES

Agroforestry involves growing trees and tree-like species, often together with crops (multi-species agroforestry or MSA systems) or livestock (silvopastoral systems). In this working paper, the focus is on values or benefits associated with traditional Pacific island tree species. A necessary first step is to define a 'tree'. Some confusion often arises in what constitutes a tree, and whether coconuts and bananas can be called trees. According to Thaman et al. (2012, p. 26), "a true 'tree' is technically any woody plant, above 3 m in height, which normally forms a single trunk or stem. Some plants, such as bananas …

Table 1. Environmental and social benefits of agroforestry.

Environmental or social benefit item	Specific types of goods and services
Environmental benefits	
Land	Land protection (control of surface and gully erosion, landslides), coastal protection, nitrogen fixation
Water	Flood mitigation, water quality protection
Air, climate modification	Carbon sequestration, windbreaks, control of salt spray, shade and temperature reduction for other plant species
Biodiversity protection	Conservation of rare or threatened species of plants and animals
Vegetation protection	Windbreaks, living fences, fire retardation
Food and food collection	Food species for which no market exists, fish sedation
Wildlife support	Habitat and food (for beneficial insects including bees, and for seed dispersers and pest insect control)
Social benefits	
Medicinal benefits	Particular types of bark, leaves and sap
Climate modification	Urban shade
Water	Water yield
Visual amenity	Varied and attractive vegetation, including flowers, attractive wildlife
Products for ceremonial and religious purposes	Drinks (kava), carving wood, canoe timber, oils (for heating, lighting, body), body ornamentation, garlands
Other non-traded products	Edible leaves, flavouring, spice, soap, perfume, tannin, dye, resin, gum, glue, latex, insecticide
Scientific and educational value	Knowledge about how individual species and multi-species agroforestry systems perform under varying site and other conditions
Future livelihood (legacy)	An asset for future generations

with no woody tissue … are really giant herbs. Shrubs are … woody plants … normally under 3 m in height … and produce new shoots or stems from the base of the plant, rather than forming a single trunk. … bamboo … is really a giant woody grass …". Notably, coconuts belong to the family Palmae, i.e. they are palms and technically not trees. Thaman et al. (2012) noted however (p. 27) that various species, including those mentioned above, are normally referred to as 'trees' in Pacific island countries.

Details have been collected on 15 traditional tree species found in Fiji and Vanuatu. Some of these are mainly found in the wild, while others are now grown in plantations. A starting point was a list of priority tree species in Fiji and Vanuatu provided to the authors by Dr Kevin Glencross (personal communication 2014; reproduced below).

> "The key priority species for Vanuatu are:
> *Endospermum medullosum*—whitewood
> *Terminalia catappa* (Bislama name: Natapoa)—Pacific almond
> *Santalum* spp. (including *S. alba*)—sandalwood
> *Flueggea*
> *Canarium*
> *Intsia*
> Exotics include *Swietenia macrophylla*—mahogany
> A similar list applies for Fiji with the inclusion of *Inocarpus* and breadfruit."

Further species were added from project visits to Fiji and Vanuatu, and based on importance assigned in reported literature.

Comments are provided below on the 15 selected tree species, drawn in particular from the series of reports edited by Elevitch (2006) in 'Traditional trees of Pacific islands: their culture, environment and use', subtitled 'Species profiles for Pacific island agroforestry—ecological, economic, and cultural renewal'. This collection of reports on some of the most important traditional tree species in Pacific islands is described by the editor as a project to educate extension agents, farmers, ranchers and landowners about native and traditional trees for crop diversification, windbreaks, coastal protection, shelter and shade, soil improvement, water conservation, livestock fodder, woodlots, food security, and many other applications. Supporting information has been obtained from web searches and research visits to Fiji and Vanuatu.

Artocarpus altilis (breadfruit). This fruit (or vegetable) food species with moderate site tolerance is important in Fiji, including in village gardens. Breadfruit has benefits in replacing food imports and in relation to community health.

Calophyllum inophyllum (dilo, Alexandrian laurel, beach mahogany, oil nut tree). According to Friday and Okano (2006), this species is hardy and is an attractive ornamental, providing shade and shelter in coastal areas. Further, "the wood is a prized timber for carving, cabinet making… traditionally used for food vessels and …storyboards …Oil from the nuts … used for medicine and cosmetics …used in varnishes and as lamp oil ... The tree is regarded as sacred in some Pacific islands." Also, "since the tree is tolerant to wind and salt spray, it has been used in coastal stabilisation."

Canarium indicum (canarium, pili nut or galip nut). Canarium nuts have a long history of social importance in the Pacific islands, and notably the Solomon Islands. They are a high-protein food and a number of medicinal benefits have been reported from consuming the nuts and from products made from the bark, e.g. for the treatment of arthritis. The timber is useful for wood carving. Thomson and Evans (2006a) drew attention to the use of canarium trees in traditional customary life, including in stories, songs and dances, and for tribal boundaries and markers. PARDI (nd) noted that "Canarium nut producers are typically smallholders, principally female, who hand pick and sell nuts as nut-in-shell or dried kernels at roadside or village markets." According to Orwa et al. (2009), the "remarkable resistance [of canarium] to strong winds makes it a good living windbreak for other crops such as bananas and papayas." Canarium is considered important for wildlife habitat. It is also highly regarded as an attractive large and spreading roadside and urban ornamental and amenity tree, providing shade and being popular with children for nut collection.

Casuarina equisetifolia (casuarina). This nitrogen-fixing species is notable for wide site tolerance, wind resistance, coastal protection, excellent quality fuelwood and as a long-term host for sandalwood.

Cocos nucifera (coconut). This very widely grown palm species, sometimes referred to as the 'tree of life', has many useful market products and non-market goods and services. The main export product is copra, used for oil, dessicated coconut and other products. The attractively grained timber of older 'trees' is widely used in some countries for construction purposes and for producing souvenir products for tourists. The fruit and flowers are used to produce various alcohol products (e.g. cocovodka and tuba in the Philippines). Coconut palms are well suited for agroforestry and silvopastoral farming systems.

Endospermum medullosum (whitewood). Primarily an important Vanuatu timber species, whitewood has strong export potential. Thomson (2006) noted that fallen leaves of whitewood break down quickly so the species is useful as a soil improver to provide organic matter, and also that the extensive lateral surface roots make whitewood a "very good soil stabiliser". It is also useful for wildlife habitat, including as a food source for pigeons, and has an ornamental value in the landscape.

Flueggea flexuosa (poulumi or namamau). This relatively short and rapid-growing timber species is well suited for producing durable round timber quickly in multi-species plantings. It is also effective as a windbreak species. Flueggea has potential in agroforestry systems with whitewood, canarium and mahogany, and as a shade tree for cacao (Thomson 2006).

Hibiscus tiliaceus (beach hibiscus, coast cottonwood). Elevitch and Thomson (2006) reported that this species grows particularly well in coastal and near coastal areas. It is not considered a timber species but has rapid growth and is adapted to a wide range of soil conditions. It is used for coastal protection, windbreaks, hedges, trellises and living fences, including around pastures. The timber is used for craftwood, canoe parts, cordage and fuelwood, and it is a medicinal species.

Inocarpus fagifer (Tahitian or Polynesian chestnut). This species is common as a wild species in Fiji, particularly on wet sites. According to Pauku (2006), "the edible kernel is an important indigenous food in many island countries in the Pacific. … The nutritious kernels have protein and carbohydrate contents of about 5% and 22% respectively." Also, "almost every part of the plant has been used traditionally. Leaves and bark are mainly used for medicinal purposes, while fallen branches are used for firewood. Even green wood is used to dry copra. The wood is also used for crafts, tool handles, canoes, and light construction." Polynesian chestnut is an ideal urban species, providing urban beautification and shade for parks and streets, and nuts which can be collected. It provides shade for crops and is a food source for birds and flying foxes as well as a nesting site for birds. The extensive network of lateral roots extends a long distance from the trunk, which is useful for stabilisation of coastal land.

Intsia bijuga (vesi; also known as kwila, merbau, Borneo teak, Moluccan ironwood and various other local names). This species grows naturally in various countries in Asia and the Pacific and products made from this species have been widely traded internationally. Mostly harvested from the wild in the Pacific islands, it is a relatively slow-growing species suitable for low-rainfall sites. It produces timber highly regarded for wood-carving purposes.

Mangifera indica (mango). According to Bally (2006), mangoes are an esteemed fruit and used in a wide variety of food dishes. They "are a highly nutritious fruit containing carbohydrates, proteins, fats, minerals, and vitamins … are particularly high in vitamin A" and "make a significant contribution to diet of many Pacific islanders that primarily have a starch-based diet." Also, the trees are relatively wind resistant and are sometimes used as windbreaks, and are useful for shade for stock in silvopastoral systems. Bark and leaf infusions, and preparations from green and semi-ripe fruit, are used for medicinal purposes in several PICs. Aged trees with declining fruit yield are widely used as a timber source.

Santalum austrocaledonicum and *S. yasi* (sandalwood). In the past, sandalwood was mostly harvested in the wild but it is now a highly favoured agroforestry species. It is dependent for survival on a host species and is usually grown with a pot host then a short-term and long-term host species. High-value marketed products from sandalwood include carving timber and heartwood for fragrant oil, perfumes and incense. The leaves and nuts are edible by people and animals.

Terminalia catappa (natapoa, tropical almond or sea almond). Early yield of nutritious nuts (after about three years) and environmental properties make this a highly regarded Pacific island species. As noted by Thomson and Evans (2006b), this large spreading tree "is tolerant of strong winds, salt spray and moderately high salinity in the root zone. .. very important for coastal communities, providing a wide range of non-wood products and services. It has a spreading, fibrous root system and plays a vital role in coastline stabilization. … widely planted for shade, ornamental purposes and edible nuts. The timber makes a useful and decorative general-purpose hardwood and is well suited for conversion into furniture."

Theobroma cacao (cacao, cocoa). This species is grown mainly for cocoa beans for the production of cocoa, chocolate and drinks. By-products from bean processing are useful organic fertiliser. The extensive root system and recuperative abilities of cacao plantations, even after years of neglect due to low bean prices, make for flexibility of management and relatively low risk.

DISCUSSION AND SUGGESTIONS FOR FURTHER RESEARCH

The importance of environmental (including ecosystem) benefits, particularly with respect to soil, water, air and biota, is widely recognised in relation to forestry and agroforestry. Social benefits arise in the form of goods and services valued by people, whether or not these are traded in markets. Of particular interest would be a study of non-market benefits of species with notable watershed and coastal protection values.

Both single-species forestry and multi-species agroforestry, as forms of land use, have much to offer society in Fiji and Vanuatu. A number of tree species have been identified as high priority for growing in MSA systems. Agroforestry plantings have the potential to generate a wide range of non-market benefits, such that their value to society can be substantially greater than their private benefits to planters, a fact which justifies public funding support for agroforestry development. The externality benefits of growing these species can be estimated in financial terms, or at least rated on an ordinal scale and considered alongside financial benefits, in arriving at policies for agroforestry support.

Methodology for non-market valuation has been widely researched, and the strengths and weaknesses of the various valuation techniques are now well documented, such that the methodology has reached a level of acceptable precision for policy support. Substantial progress has been made in the last 25 years in the development of databases of environmental values, which can be used in benefit transfer methodology for estimation of non-market values. Given this progress, there seems to be a real possibility to carry out a search of non-market value databases and apply benefit transfer methodology to obtaining credible per capita estimates of at least some of the non-market values, and integrate these with financial values, to support policymaking on agroforestry development in Fiji and Vanuatu. A household survey and a key informant survey (especially of government and Pacific Community (SPC) officials in Fiji and Vanuatu) could be conducted, in association with this method of non-market valuation, to gain greater insights into local perceptions of the importance of non-market benefit categories for novel Pacific island tree species.

Non-market valuation approaches with greater precision—including state preference methods—could probably also be used, but some experimentation would probably be needed, and the cost would be considerably higher. A more ambitious approach to environmental and social valuation would be to apply say environmental choice modelling to generate original financial estimates of the social and environmental benefits of growing novel Pacific island tree species in monocropping and multi-species plantings. These value estimates could then be integrated with findings of estimates of market values to support policy analyses for Fiji and Vanuatu.

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5. Opportunities for and constraints to agroforestry expansion on underutilised land in western Viti Levu, Fiji

Robert Harrison, Steve Harrison and Tevita Kete

Abstract

Fieldwork in western Viti Levu, Fiji reveals that a substantial area of land is underutilised, including in the sugarcane belt. In many cases, the allotments leased contain some sloping land that is not suitable for sugarcane production but would be suitable for agroforestry. Opportunities for agroforestry arise from: a large number of useful tree species (including high-quality timber species) and food crop species; a chance to generate potentially large private and social benefits; and a history and skill base in agroforestry. The constraints appear to include: relatively low rainfall in winter months, limiting species choice; degraded land due to deforestation and frequent wildfire; insufficient resources among landholders for establishing agroforestry plantings; high management complexity of mixed-species agroforestry systems, including for crop protection; relatively low domestic timber demand and prices; supply and value chain issues for non-timber agroforestry products; land tenure uncertainty for long-rotation land uses; and lack of a lead agency for promoting this land use. Wildfire appears to be a major disincentive to establishing forestry and agroforestry, with numerous reasons for lighting fires being identified. The constraints identified suggest scope for policies to create a more favourable situation for forestry and agroforestry investment. Some relevant facilitation measures include: trials on improving degraded land at planting sites; a coordinated effort on wildfire control, probably at community level and including a fire surveillance system; improving the institutional environment for agroforestry planting, for example by developing a regional or national agroforestry statement or plan; increased use of demonstration sites and provision of extension services; provision of more financial information on the expected costs and returns from agroforestry plantings; and carefully designed financial assistance measures.

INTRODUCTION

The ACIAR project 'Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu' (ADP/2014/013) has been designed to examine potential alternative uses of underutilised sugarcane land in Fiji and senile coconut plantations in Vanuatu. The focus of this paper is limited to Fiji.

The sugar industry has been a major employer and source of export revenue in Fiji since the late 1800s. Decreasing prices and uncertain future markets in Europe have led to a contraction of the industry during the last 30 years. At the same time, there has been increasing urbanisation in Fiji, and a substantial area of land appears to be underutilised at a time when a relatively large expenditure is being made annually on food imports.

While the sugar industry is currently depressed, it is recognised that new markets for sugar may arise, new value-added products may be produced, and greater production efficiency may be achieved in the industry. Therefore, investigation of potential agroforestry sites was not limited to land where sugarcane growing may cease. Rather, the project focus was on areas with underutilised land with suitable soil type, climate, access to markets and other factors similar to those found in the sugar-growing areas. For logistical reasons, the study area chosen was the Fiji Western Division, which includes the provinces of Ba, Nadroga-Navosa and Ra in Viti Levu.

Historically, agroforestry has been widely practised in Pacific island countries, particularly in the form of homestead and village agroforestry, with a high level of food self-sufficiency in these countries. During the colonial period, monocropping was promoted to generate revenue from exports, with a decline in the area under agroforestry. In Fiji, copra became a major export product, followed by sugar. In recent years the export prices for copra and sugar have declined, hence there is interest in alternative profitable land uses. At the same time, population growth and urbanisation have created a situation of large food imports, and the potential environmental and social benefits of renewed agroforestry development have been recognised.

Since the 1970s, researchers in the Pacific islands have highlighted the many advantages of various forms of agroforestry and silvopastoral systems, and provided detailed descriptions of suitable native or traditional tree species. Notable publications include those of Thaman and Clarke (1993), Elevitch and Wilkinson (2000), Alavalapati and Mercer (2004), Elevitch (2006), Kumar and Nair (2006), Nair and Garrity (2012), Thaman et al. (2012) and Atangana et al. (2014).

The objective of this paper is to examine the opportunities for expansion of multi-species agroforestry (MSA) systems in the Fiji Western Division in Viti Levu, and the impediments to increased use of land for this purpose. The paper first examines availability of land resources, climatic conditions and suitable tree and crop species in the Western Division. Some general observations are then made about expansion of smallholder forestry and agroforestry in developing countries, based on literature review. Next, some observations and speculations are made about the underutilisation of rural land in the Fiji Western Division and the potential for agroforestry expansion. Concluding comments follow.

AGROFORESTRY OPPORTUNITIES IN WESTERN VITI LEVU

This section examines the land, labour, capital, management and technical and institutional resources available for agroforestry expansion in western Viti Levu. Some observations are made about suitable species for the site conditions.

Climate in western Viti Levu

The Western Division of Viti Levu has a tropical climate with hot humid 'summers' and relatively dry 'winters'. Table 1 shows monthly rainfall for Nadi and Lautoka, and for Suva for comparison. The average annual rainfall in Nadi is 1,809 mm and in Lautoka is 1,868 mm, much less than in Suva (3,041 mm). Both Nadi and Lautoka have an average rainfall of less than 75 mm in June, July and August. Rakiraki in the north of Ra province has a higher annual rainfall than Nadi and Lautoka (averaging 2,352 mm), though rainfall further south in the province is lower.

Climate suitability and species–site matching

A number of the tree species described in Elevitch and Wilkinson (2000) and Elevitch (2006) would be well suited to growing conditions in western Viti Levu. Setting aside for the moment the other important factors for species–site matching, annual rainfall of over 1,800 mm is considered suitable for tree growing but the three-month dry period with relatively high daily maximum temperatures reduces the number of suitable species. Some Pacific island species are described in the species profiles in Elevitch (2006) as tolerant of three or more months of dry weather, and are likely to grow successfully in these areas, including vesi, sandalwood, cocoa, casuarina and mango, the last two species being said to tolerate drought of up to eight months, with mango fruiting best in areas with a well-defined winter dry period. While no pine species are listed in the traditional tree list of Elevitch (2006), Caribbean pine (*Pinus caribaea*) is planted widely in Fiji, Thaman (2011, p. 90) saying this "is the major species used in reforestation of degraded grassland areas in Fiji and parts of Vanuatu". There is also strong interest in planting the hardy biofuel species pongamia (*Millettia pinnata*), with about 200,000 ha having been planted to date by Biofuels International Fiji (Sapp 2014). Further, there is interest in expanding the area under coconuts in Fiji (Republic of the Fiji Islands 2013). Crop species which are relatively tolerant to dry periods and which may be combined in agroforestry systems include cassava, pineapple, upland taro and possibly kava.

Notably, eucalypt and acacia timber species would probably be highly suited to even difficult sites in western Viti Levu but these species are generally not considered appropriate for growing in the Pacific islands. Two exceptions are *Eucalyptus deglupta*, the only eucalypt found in the northern hemisphere and native to New Guinea and Mindanao in the Philippines, and *Acacia spirobis*, which grows naturally in Australia, Vanuatu and New Caledonia, and is a suitable host species for sandalwood.

Sugar industry contraction, land classification and land availability

Western Viti Levu in Fiji has a history as an important sugarcane-growing area. The latitude is about 17°S, similar to that of Cairns in north Queensland. Important cities include Nadi (with an international airport), Lautoka and Ba. The extended dry period limits the range of trees species and crops which can be grown relative to the wetter eastern side of Viti Levu, the land in the north near Ra being an intermediate zone climatically. Much of the area in western Viti Levu is deforested and low-quality grassland is found on the more sloping areas. Soil quality in much of the flat, or only moderately sloping land, particularly that in which sugarcane can be grown, is in general adequate for agroforestry.

It is notable that in western Viti Levu a large area of agricultural land is not in production, which raises questions of why there is not more intensive use of the land given that Fiji has substantial food imports. Prior to 1990, Fiji traditionally had 92,000 ha under sugarcane and produced on average 460,000 tonnes of sugar a year from four mills (Krishnamurthi, nd), production peaking at "just over 500,000 tonnes in 1986, nearly approaching the target of 550,000–600,000 tonnes projected in Fiji's ninth development plan (DP9) for 1986–1990" (Narayan and Prasad 2003, p. 3). Vaniqi (2012) in a conference paper titled 'The Fiji sugar industry—government response to the crisis and vision for the future' noted a sugar price decrease of 36% in the Europe export market. Vaniqi further noted that four mills were still operating in 2011, serving 13,251 growers and producing 166,669 tonnes of sugar grown on 42,855 ha. (Three of the mills are on Viti Levu and one is on Vanua Levu.)

A worst-case sugar market situation was reported by Pareti (2014), who stated that "our investigations

Table 1. Monthly average rainfall at Nadi and Lautoka, and Suva for comparison; and average maximum and minimum temperatures for Nadi and Suva.

	Lautoka	Nadi				Suva			
	Rainfall (mm)	Ave. max. temp. (°C)	Ave. min. temp. (°C)	Rainfall (mm)	Rain days >0.1 mm	Ave. max. temp. (°C)	Ave. min. temp. (°C)	Rainfall (mm)	Rain days >0.1 mm
January	298	31.6	22.7	299	18	30.6	23.6	315	23
February	303	31.5	23.0	302	18	31.0	23.8	288	22
March	322	31.1	22.6	324	19	30.6	23.5	371	23
April	170	30.6	21.7	163	12	29.7	23.1	390	22
May	86	29.8	20.1	78	7	28.3	21.9	267	20
June	70	29.2	19.3	62	6	27.6	21.4	164	18
July	47	28.5	18.3	46	5	26.5	20.4	142	18
August	60	28.7	18.4	58	5	26.6	20.5	159	17
September	85	29.4	19.3	77	6	27.0	20.9	184	27
October	98	30.2	20.4	103	9	27.8	21.7	234	19
November	143	30.9	21.5	138	11	28.8	22.5	264	19
December	186	31.4	22.1	159	13	29.8	23.2	263	21
Total	1,868			1,809				3,041	

Source: Adapted from Fiji Meterological Service records.

show that Fiji's sugar currently fetches around €400 (A$570) in the EU market. Once our current trade agreement under Lome [Convention] lapses, Fiji's sugar will automatically cop duty of €339 per tonne. This leaves Fiji with a mere €61 per tonne in revenue, rendering the entire sugar market unviable." A contrasting view is that China may become a major buyer, Chaudhary (2014) commenting on "negotiations that could result in excess of 100,000 tonnes being sold at prices similar to that offered by the EU" (presumably as an annual demand quantity). A proposal has been made to establish a sugar refinery in Labasa (in Macuata Province of Vanua Levu) under a cooperation arrangement with Chinese investors (Bolaitamana 2014).

The Pacific Community (SPC 2012) reported the establishment of the European Union (EU)-funded Improvement of Key Services to Agriculture project "to cushion the economic and social impacts of the sugar restructuring by supporting a diversified, market-driven agriculture … through the assistance to fair-trade and to reduce their dependence on cane farming by assisting them to diversify into horticultural crop opportunities." It was further noted that the project would create "new opportunities for import substitution in the horticulture sector, while addressing the land-use management and sustainability challenges facing the sugar belt region."

While sugarcane production is still highly important, there is considerable interest in growing other horticultural crops, evidenced for example by the recent publication of 'gross margins for selected fruit, vegetable and root crops for the sugarcane belt in Fiji' by Leslie (2013) for SPC. Also, as noted by SPC Land Resources Division (2013), the EU-funded project will "assist the cane producers to supplement their income by utilising land that is under-utilised, as well as farmers who are no longer growing cane and other farmers who live and farm in the periphery of the cane belt".

Fiji has a comprehensive land use capability classification system based on that of New Zealand but modified in 1977 to suit Fiji's conditions, and described in the Department of Agriculture (nd) 'Land Use Capability Classification System: A Fiji guideline for the classification of land for agriculture'. Land is divided into eight classes based on a number of criteria, including slope, drainage, soil depth, water-holding capacity, extent of erosion, fertility, stoniness, rainfall and altitude. Classes I to III are considered suitable for ploughing and cropping, IV for low intensity cropping, V to VII for pastoral and forestry use and VIII only for protection purposes. Ketedromo (2013) conducted land-use mapping for the relatively small (13,819 ha) Sabeto catchment located 8 km from Nadi town. A total of 39% of the land was found to be arable (classes II–IV, with slope not more than 15%) and an additional 56% was classed as suitable for pasture and forestry (classes V–VII with slope ranging from 16% to 35%). Ketedromo (2013) noted a number of vulnerabilities for the community in the Sabeto catchment, including food insecurity and

Figure 1. A breadfruit, pineapple and cassava agroforestry planting near Nadi. Photo: Robert Harrison

reliance on imported and less nutritional food, limited communication and access roads, increased incidence of disease outbreaks, increased incidence of landslides, increased flooding of food gardens, and reduced crop yields.

The provinces of Ba (2,634 km²), Nadroga-Navosa (2,385 km²) and Ra (1,341 km²) comprise the Western Division of Viti Levu, with a total area of 636,000 ha. It is clear that the 42,855 ha used for growing sugarcane is a relatively small proportion (less than 7%) of the land area of the Western Division. A detailed land classification and current land-use study would be required to determine the area of land which would be suitable for agroforestry, although visual inspection in the division suggests that a substantial area would be suitable.

Some of the land in the Western Division is currently covered with native or plantation forest and some large reforestation projects have commenced recently. The Nakauvadra community-based reforestation project of Conservation International, located in the far north of Viti Levu in the Ra Province, commenced in 2010. The project is designed to reforest 1,135 ha of degraded grasslands with a mixture of teak (*Tectona grandis*), mahogany (*Swietenia macrophylla*) and 29 native species. The native species have been selected on the basis of their ability "to survive and grow in the conditions of the project site" and "to encourage natural succession to help achieve the long-term biodiversity and climate goals of the project" (Conservation International 2013, p. 40). Vesi (*Intsia bijuga*), sandalwood (*Santalum yasi*), Pacific kauri (local name dakua; *Agathis macrophylla*) and casuarina (local name nokonko; *Casuarina equisetifolia*) are included in the native species list. "Teak seedlings are planted along mid-slope as they are more suited to the harsh environment and on plots that are entirely comprised of mission grass (*Pennisetum polystachyum*). Native seedlings are planted at the bottom of the ridge, near waterways and remnant forest patches. From pilot plots we have found out they tend to do well in sheltered or less extreme environments" (Conservation International 2013, p. 41).

The Reforestation for the Degrading Foothills of the Sugar Belt project (Reforest Fiji), which commenced in 2014 and is based in Lautoka, is funded by the EU with a budget of €9 million over 46 months. The project is being implemented by SPC, and according to an advertisement for a project manager, the objective is to improve watershed management in the sugarcane belt of Viti Levu and generate community income through reforestation. In particular, the aim is to reverse continuing land degradation on the sloping foothills within the three sugarcane sectors of Drasa, Koronubu and Malolo, by using community resources to generate additional community income for landowners and sugarcane growers. The project is designed to reforest 6,000 ha, teak being a key species. The project will no doubt face some major challenges, for example in terms of availability and genetic quality of seedlings, and silvicultural management.

CONSTRAINTS FOR SMALLHOLDER TREE PLANTING AND FACILITATION MEASURES

In considering strategies for agroforestry promotion in Fiji and Vanuatu, it is necessary to consider constraints on planting and measures to overcome them. There is an extensive literature on measures for supporting tree planting in developing countries, particularly in relation to single species (monoculture) planting. The literature on these schemes is highly relevant to agroforestry promotion, although typically greater complexity and additional problems need to be addressed. The focus here is on relatively small area (i.e. smallholder) planting rather than industrial planting.

An assessment of impediments to tree planting has been provided in a study of adoption of Australian tree species in the Philippines by Venn et al. (2000), in which the following summary table was produced. In this table, tree planting impediments identified in various countries are divided into five groups, namely profitability concerns, resource constraints, market constraints, property rights constraints and other impediments. The circumstances of growing Pacific island species in Fiji in MSA systems obviously differ from those faced in planting exotics in these other countries, but the list of impediments does provide a useful starting point for identifying potential constraints.

While an investigation of impediments to forestry in general, and agroforestry in particular, is critical to understanding the current biological and socio-economic circumstances in which planting programs are promoted, it is equally important to have an understanding of facilitation measures which can be adopted to overcome these impediments.

From research in a number of developing countries in Asia, Byron (2001) concluded that four particular conditions must be satisfied simultaneously for farmers to establish tree plantations. He argued (p. 220) that "the 'locks' or impediments to farm forestry, when generally defined, are remarkably universal. They include secure property rights to land and tree crops; a viable production technology; capacity for crop protection; and adequate markets."

A broader but overlapping list of factors influencing landowners' decisions to adopt tree growing has been provided by Kanowski et al. (2014, p. 13–18, Word version). The factors are grouped into: landowner preferences and decision processes; social organisation and resource endowments; market incentives and external links; biophysical factors; and risk and uncertainty.

Table 1: Frequently cited impediments to the adoption of new plantation technology

Impediment	Philippines[1]	Philippines[2]	Philippines[3]	Philippines[4]	Philippines[5]	Thailand[6]	Laos[7]	Bangladesh[8]	Nepal[9]	India[10]	India[11]	India[12]	India[13]	India[14]	India[15]	China[16]	Indonesia[17]	Kenya[18]
Profitability concerns																		
Lack of information about profitability		X		X														
Difficulty and cost of tree protection								X	X			X						
Expectation of low returns				X		X								X			X	
Long payback period and high private discount rate			X							X								
Resource inputs																		
Land and climate constraints	X							X	X			X						
Lack of labour								X	X			X						
Unavailability of seedlings					X		X	X	X								X	
Lack of knowledge and extension information					X		X	X	X			X						
Lack of access to finance	X							X		X		X					X	
Market constraints																		
Lack of timber markets	X				X	X					X	X		X				
Lack of market recognition of Australian species																		
Timber properties of Australian species		X																
Market distortions of crop subsidies																		
Property rights constraints																		
Landlord-tenant relationships, uncertain timber rights										X								
Insecure property rights to land and trees	X								X									
Impediments to log transport		X																
Other government regulations and disincentives						X									X		X	
Attitudinal impediments																		
Preference for multi-purpose trees	X				X	X		X	X									
Accessibility of nearby natural forest	X					X												
Negative attitudes to Australian species					X						X		X			X		X
Negative extension information			X				X				X							

[1] Pasicolan and Tracey (1998)
[2] Harrison and Herbohn (1999)
[3] Margraf and Milan (1996)
[4] Aguilar (1986)
[5] Nixon (2000)
[6] Amyot (1988)
[7] Wittrock (1996)
[8] Khaleque (1988)
[9] Dixit (1988)
[10] Shah (1988)
[11] Saxena (1992)
[12] Dhage et al. (1998)
[13] Chaturvedi (1988)
[14] Negi et al. (1996)
[15] Lal et al. (1997)
[16] Haishui (1988)
[17] Gunawan et al. (1998)
[18] Gustavsson and Kimeu (1992)

Source: Venn et al. (2000).

Facilitation of forestry and agroforestry calls for a consideration of appropriate policy instruments, tailored to the particular impediments and designed to achieve desired outcomes. A large number of policy instruments or support measures, particularly in terms of community forestry schemes, subsidised planting (e.g. planting grants) and in-kind assistance (e.g. provision of free seedlings, assistance in tree planting), have been used to promote tree planting.

A number of investigations have been conducted into the potential for a major increase in the production and marketing of particular Pacific islands tree species. These have, to varying degrees, included business cases, implementation plans and recommended support measures. Some examples are those for expansion of plantations of hoop pine (*Araucaria cunninghamii*) on the Atherton Tablelands in north Queensland (Harrison et al. 2006), cocoa (*Theobroma cacao*) in Vanuatu (McGregor et al. 2009; Lloyd 2014), sandalwood (*S. austrocaledonicum*) in Vanuatu (Page et al. 2012), canarium nuts (*Canarium indicum*) in Papua New Guinea (Cornelius et al. 2014) and whitewood (*Endospermum medullosum*) in Vanuatu (Virannamanga et al. 2015). A detailed analysis of constraints, and of enabling environments and facilitation measures, discussed in the reports mentioned above, would provide valuable insights into how to promote forestry and agroforestry in Fiji and Vanuatu.

IMPRESSIONS OF AGROFORESTRY CONSTRAINTS IN WESTERN VITI LEVU

Looking at the landscape in western Viti Levu in Fiji in August 2014, an immediate impression was of agroforestry around villages—located typically on or near the coast and close to rivers and creeks—and small patches of sugarcane, but otherwise a brown land was observed with much of the area unused or underused. Away from watercourses, it is difficult to find examples of successful agroforestry, and some agroforestry sites appear to have been neglected or abandoned. This raises an obvious question: why is there so little forestry, agroforestry, or cropping given the availability of land? While it is difficult to provide a definitive answer to this question, a number of potential reasons can be advanced.

Unsuitable climate

Western Viti Levu has moderately high temperatures and an average rainfall of about 1,800 mm or more per year, though with a seasonal dry period from June to September. This meets the requirements for a limited number of agroforestry species (timber trees, fruit trees, some root crops) as stated for example in the species profiles for Pacific islands agroforestry reported in Elevitch (2006).

Unsuitable land

Distinct terrain differences can be observed from relatively flat land near the coast to steep land in the centre of Viti Levu. The low to moderate sloping land appears suitable for cropping, and much has been used for growing sugarcane. Also, large areas appear suitable for forestry and some intercropping, though a study of soils maps would be needed to confirm this. To date, only a small area appears to have been assessed in terms of the Fiji land-use capability classification system. Much of the land in the Western Division was originally forested, although there has been some loss of topsoil with deforestation, sugar cropping and frequent fires. On steeper sites, it may be necessary to adopt wide spacing, especially for fruit tree species, and perhaps some land 'treatment'—e.g. ripping, hand tilling, green manure cropping, building up organic matter at planting sites—and in extreme cases, using the sloping land technology of Asia or even the barren land planting technology as developed for example in Vietnam. Such land preparation would add considerably to the cost of tree and crop establishment. From a research perspective, further assessment of land suitability and site preparation requirements would aid the choice of priority planting sites. The Fiji Government is actively conducting land suitability assessment, e.g. see Department of Agriculture (nd) and SPC Land Resources Division (2012).

Insufficient resources for establishing agroforestry plantings

Landholders may be constrained from practising agroforestry by a lack of finance or labour. Typically, farmers in Fiji are not regarded by the banks as creditworthy, and in some contexts are classified as unemployed (Page et al. 2012). Although much of the land is already cleared of vegetation, establishing multi-species plantings can involve substantial capital outlays for preparing planting sites, acquisition and planting of seedlings, and weed control. Revenue generation from timber trees typically takes 20 to 30 years, and from fruit trees about three to five years. Some vegetable and fruit species suitable for relatively dry sites, including cassava, pineapples and upland taro, come into production within two years. In general, farming households need to have other areas currently in production or financial reserves to establish agroforestry. Agroforestry provides opportunities for use of both household labour and casual labour, however there appears to have been a decline in the availability of rural labour, with urban migration for increased income and improved lifestyle. While timing of planting (best at the beginning of the wet season) and fruit harvesting is probably critical, there is in general considerable flexibility in the timing of labour inputs for other agroforestry activities, which can fit in with other farm and off-farm work by landholders.

High complexity of MSA systems

Relative to monoculture forestry, agroforestry systems have greater complexity in terms of species–site matching, establishment, maintenance, harvesting and marketing. The information available for Pacific island tree species that are not widely adopted commercially in plantations, including for example site requirements, growth rates, optimal silvicultural treatments and harvest age, has not been widely researched and little extension information is available. The increased complexity may well be a reason why governments favour monoculture forestry, with species for which production systems are well known and for which timber has established market recognition. This could also be a reason why farmers are cautious about experimenting with agroforestry on their land.

Lack of knowledge about agroforestry systems

Establishing and managing agroforestry systems requires some necessary skills, especially where a number of species are being combined and the soil type and climate at the planting site are less than ideal. Site preparation and ensuring high survival rates on out-planting can be difficult. Production of own seedlings and reluctance to use fertilisers can add to these problems. Where landholders produce their own seedlings, seedling physical and genetic quality is often low. Seedlings are often lank, etiolated, overgrown, with coiled or damaged root systems, or with insufficient sun hardening (Gregorio et al. 2015). The visit to Fiji revealed that finding agroforestry demonstration sites was difficult and there was probably little communication about agroforestry practices between neighbours.

Difficulties in making land-use transition

While export prices for sugar from Fiji have fallen, and future market opportunities are uncertain, measures are being taken to reduce production costs and there is still a possibility of some price recovery. In this situation, the Fiji Sugar Corporation is anxious to keep intact the land areas suitable and available for sugarcane. A substantial area of land used for sugarcane and other crops is under lease, which may impede changes in land use. Some of the observed 'unused' land may be under fallow, i.e. land resting between cropping cycles for restoration of nutrients and to reduce the need for fertiliser inputs. Falling sugar prices and increasing farm input prices, including for synthetic fertilisers, would favour increased use of fallow systems. Even if this is not the case, changing land use can have financial implications for the sugar industry and individual smallholders. Some capital in the form of sugar mills and farm plant and machinery is dedicated to sugar production, and this 'stranded capital' presents a barrier to land-use change. Notably, the on-farm extent of mechanisation for sugarcane growing and harvesting appears to be relatively low. Traditionally, areas operated by sugarcane growers have been small (about 4–5 ha), work animals have been used for land preparation, and most cane harvesting has been by hand cutting not using machinery.

Low timber profitability

With a low domestic population and relatively low timber use in houses (compared with concrete block and iron roofing) as well as low demand for fuelwood (due to the mild climate and relatively high coverage of electrification in Viti Levu), Fiji is dependent on export markets to sell timber. Felling of native forests is now tightly regulated, and the area under timber plantations is relatively small. Some opportunities have been identified where overseas timber demand is high, including for sandalwood (with strong demand for heartwood for carving, sandalwood oil and incense sticks), vesi (a favoured carving timber) and at least potentially whitewood as a panelling timber. These species are well suited to growing in MSA systems on relatively dry sites, and in fact sandalwood is hemi-parasitic and hence can only be grown in mixed-species plantations.

Supply and value chain issues for non-timber agroforestry products

While timber production generally involves a long wait for any revenue, agroforestry plantings often include fruit, nut, vegetable or other species which generate food or cash income more quickly. However, profitability depends on having access to markets and acceptable prices. In rural areas, there appears to be a relatively abundant supply of low-price fruit and vegetables. In larger urban areas, food prices may be higher and there is greater reliance on imported rice and other foodstuffs. Producers of small and infrequent quantities of fruit and vegetables tend to be at a disadvantage in urban markets, and often have to sell through middlemen who pay low farm-gate prices and gain large price markups.

Property rights limitations

While overall availability of land does not appear limiting in western Viti Levu, or elsewhere in Fiji, access to this land by individuals or groups interested in establishing multi-species plantations may be impeded by the land tenure system. For example, leasees would be likely to avoid tree planting if the expected harvest age falls outside their property rights duration. Also, leasees may be constrained to conducting activities explicitly specified in their leases, which may not include forestry. The system of property rights to land use in Fiji is complex and politically sensitive. As noted by Prasad and Tisdell (2006, p. 14), "the exclusive ownership of natural resources by the indigenous Fijians is communal and not private. The use rights which are deemed private can be in the form of land leases, fishing licenses, mineral exploitation rights and logging rights. The point of contention, however, is the security of these use rights."

Concern over the risk of wildfire

Uncontrolled fires pose a risk for forestry and agroforestry plantings in western Viti Levu. A visit during late winter in 2014 revealed fire damage to plantations and even power poles (Figure 2). A mango–cassava planting was observed in which the mango trees had fire damage (Figure 3). Destruction of trees which have been managed for several years would certainly be discouraging for landholders. There are many causes of such fires. King (nd, c. 2001) identified 14 reasons why local people in Navosa province (near Nadi) light fires:

- to clear land for planting;
- to promote the growth of new grass;
- to find and harvest wild yams;
- to help grow certain 'wild' green vegetables;
- to help with fuelwood harvest;
- to keep wild pigs away from gardens;
- to help hunt wild pigs;
- to clear tracks (of obstructions and thorny vegetation) for both people and animals;
- to help harvest 'wild' turmeric;
- to clear land for pine planting;
- to help control or find domestic animals;
- to temporarily improve fertility;
- to help control pests (especially snails, slugs and army worms) and diseases (especially anthracnose and yam rot, mildew on cassava);
- to remove undesired vegetation from rangelands.

King further noted that "wildfire is commonly accepted a normal event and no attempt is made to alter the course of uncontrolled fires, which in most cases burn uphill away from the villages which are mainly located in river valleys", and that frequent burning reduces fuel loads and fire intensity.

It would appear that forestry and agroforestry plantings can be protected from fire, but this can require considerable effort, and is perhaps best managed in community plantings where assigned fire wardens can be appointed, as in the Conservation International project in Ra province.

Other challenges in crop protection

Particularly where high-value products are grown on land not close to house sites, pilfering of products (e.g. planted seedlings, fruit and nuts, timber) is a risk. There can be damage from livestock on sites that are not fenced, e.g. cattle apparently like to graze on young sandalwood trees.

Lack of a forestry or agroforestry culture

Pacific islanders have strong traditions of fishing and low-input cropping (including coconut production) as well as subsistence-level village agroforestry. While timber has been an important export product, this has mostly been from native forests and there is less experience and perhaps less interest in plantation forestry and forestry–intercrop combinations.

Lack of institutional support for agroforestry

Increased plantation forestry is clearly an important priority in Fiji and perhaps an activity where the government can make more progress than agroforestry. Relatively large areas of single-species

Figure 2. Infrastructure damage due to fire. Photo: Robert Harrison

Figure 3. A mango–cassava plantation neglected after fire damage. Photo: Robert Harrison

plantations are no doubt a more efficient way to produce large volumes of merchantable timber. In the past, the Department of Forests has been concerned with timber plantations and the Ministry of Agriculture, Rural and Maritime Development and National Disaster Management has been the main agency for promoting agroforestry. However, the Ministry of Agriculture has recently changed its focus to timber plantations and agroforestry lacks an institutional 'champion'. It is notable that the large EU reforestation project, and to some extent the Conservation International community forestry project, have a focus on single-species plantings.

DISCUSSION

There appear to be strong reasons for agroforestry expansion in western Viti Levu. However, the above discussion suggests there may be major constraints to the adoption of agroforestry, such that intervention measures may be justified if it is judged that agroforestry is to be promoted.

Low adoption of agroforestry may be due to lack of knowledge and confidence about establishing MSA plantings, perceived difficulties in changing land use, or perceived risk of low returns. Indeed, profitability could turn out to be low due to unsuitable species mixtures for planting sites, low genetic quality of planting materials, poor initial establishment, low yields due to inadequate crop protection, a long wait for returns, weak markets, or rent capture by middlemen (i.e. middlemen gaining a large share of revenue generated). Crop loss—from pests and diseases, wildfire and theft—can be limited through appropriate crop protection practices, but may require scientific and legal support. It may be that interspersing silvopastoral systems with other forms of agroforestry would help reduce fire damage.

Overall, it is probable that a number of the factors contribute to land underutilisation in western Viti Levu, and the interacting effect of these constraints may make the growing of multi-species agroforestry systems 'too hard'. Landholders with a genuine interest in multi-species plantings may need to have greater confidence in the physical and financial performance of these plantings to commit to investing their funds and labour in these ventures.

A number of policy measures may need to be considered if agroforestry is to be promoted, e.g. in terms of financial support, provision of high-quality planting material, community organisation and capacity building, information provision (e.g. through demonstration sites), and market development.

SUGGESTIONS FOR FURTHER RESEARCH

A number of uncertainties exist with respect to constraints on agroforestry adoption, and several areas of further research can be identified.

1. Investigate Fiji's land-use policy, and the land capability classification maps if available for western Viti Levu, to identify priority planting areas for agroforestry.
2. Discuss agroforestry options in the Western Division of Viti Levu with key informants, including government officials, SPC staff and participants in international agencies conducting agroforestry and related projects, including the EU and Conservation International.
3. Conduct a survey of landholder attitudes to establishing MSA plantings.
4. Discuss the property rights regime existing on underutilised agricultural land with officers in government agencies and customary land managers.
5. Examine in more detail the perceived impediments, facilitation measures, and strategies which have been proposed in the various studies concerned with promotion of industry development based on particular tree species.
6. Identify present agroforestry sites in the study region for which visitation is possible, and the resource requirements for setting up new demonstration sites.
7. Conduct detailed assessments of the likely financial, social, environmental and institutional impacts of introducing particular multi-species agroforestry systems in western Viti Levu.

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6. Agroforestry establishment and protection on degraded land in western Viti Levu, Fiji

Steve Harrison and Robert Harrison

Abstract

The benefits of establishing mixed-species agroforestry in Pacific island countries are widely recognised. There is some underutilised land in western Viti Levu in Fiji, including in areas marginal for sugarcane where planting has ceased due to low profitability, and in areas where unproductive grasses are subject to regular burning. Two major problems are investigated in this paper, namely how to establish agroforestry on degraded sites, and how to protect planted areas from subsequent damage due to wildfire or other causes. The literature on reforestation of degraded areas provides insights into methods for 'regreening the bare hills', particularly concerning choice of tree species or mixtures and establishment methods. For fire prevention, a combination of policy measures (e.g. community awareness raising, use of fire wardens and training of canegrowers on green harvesting) and establishment of firebreaks and fuelbreaks (using fire-resistant tree species and silvopastoral areas) would appear to offer potential. Community or group action appears to offer greater potential for success than action by individual landholders. Setting up of trial and demonstration sites of agroforestry establishment and crop protection would allow the agroforestry strategies identified to be tested and landholder knowledge about agroforestry establishment and protection to be increased.

INTRODUCTION

ACIAR small research activities SRA/ADB/2012 and SRA/ADP/2013 are concerned with agroforestry development, including growing of priority 'novel' Pacific island tree species in Fiji and Vanuatu, for livelihood and environmental purposes. The area under agroforestry in these countries has declined in recent years, with increasing urbanisation and a related increased consumption of imported food. With the decline in area under sugarcane in Fiji and the ageing and lack of replanting of coconut palms in Fiji and Vanuatu, there is an increase in availability of land which could be used for establishment of agroforestry.

The project focus area for SRA/ADP/2013 is the Fiji Western Division in Viti Levu, the most populous island in Fiji. This has been and continues to be the major sugarcane-growing area in Fiji. It is relatively drier than the east of the island, much of the area having an annual average rainfall of about 1,800 mm, and relatively dry winters (long-term average of about 50–60 mm in each of June, July and August). The soil is moderately productive, and suitable for a number of priority tree species (e.g. breadfruit, sandalwood, vesi, teak, cocoa and mango) and other crops (e.g. cassava, pineapple and kava). However, there has been considerable land degradation over time due to tree clearing, agricultural use and frequent fires, and risk of further fires discourages agroforestry establishment.

It is expected that the highest quality land in western Viti Levu will continue to be used for sugarcane production and horticultural crops. However, a large area of underutilised sloping land could support establishment of agroforestry. There is strong interest in growing various Pacific island tree species for lumber, specialty timbers (e.g. for wood carving), fruit, nuts and other products, though there is limited knowledge about management and productivity of these species. This lack of knowledge is compounded by the challenges of establishing and maintaining agroforestry plantings on degraded and fire-prone land.

There is a substantial literature on reforestation of difficult sites in the tropics (mainly establishing monoculture or multi-species tree plantings), but relatively little has been written on establishing agroforestry on such sites. A few papers discuss the potential of agroforestry to improve land condition[1] and to replace forestry as a means of carbon sequestration.[2] Agroforestry is typically more demanding on site quality than forestry, particularly in relation to the growing of fruit and nut trees (for which annual harvests are taken), short-rotation high-value non-timber species, and fruit and vegetable annual or short-rotation species. This working paper examines methods to rehabilitate degraded land so as to establish agroforestry plantings in western Viti Levu, Fiji. Various approaches to preparing or conditioning degraded and fire-prone land for agroforestry planting are examined, as well as prevention of fire damage to new plantings, and suggestions are made for further research into land preparation on degraded sites and subsequent fire protection of agroforestry plantings.

While a whole-of-landscape or ridge-to-reef perspective on land use would be desirable, the attention here is on more basic questions about measures to assist agroforestry establishment and crop protection on difficult sites. Also, no particular species are considered, although it is assumed that species would be chosen which are suited to the climatic conditions of western Viti Levu, including the relatively dry winters. The attention is on sites where agroforestry rather than more intensive horticulture would be the 'highest and best use' of the land.

RESEARCH METHODS

Visits were made by Robert Harrison to Viti Levu and discussions were held with officials of the Pacific Community (SPC) in August 2014 and May 2015. Visits to western Viti Levu with Tevita Kete of SPC and on-site discussions were particularly informative.

A substantial amount of information on land use in western Viti Levu was obtained from online documents. A literature search was also conducted on reforestation of degraded land in the tropics, and on measures to prevent or minimise damage to forestry and crops from wildfire. This was augmented by discussions and e-mail exchanges with a number of experienced foresters.

THE STUDY AREA

Viti Levu is slightly further south than the town of Cairns in north Queensland. Frequent cyclones are experienced during summer. The Western Division—in which the city of Lautoka and major town of Nadi (with the international airport) are located—is in the rainshadow of the central mountains and drier than eastern Viti Levu. This is the major sugarcane-growing area in Fiji, and has a relatively dry winter in which sugarcane harvesting is carried out. Average monthly rainfall (mm) in Nadi and Lautoka is given in Table 1.

The Fiji Department of Agriculture (nd, p. 7) developed its Land Use Capability Classification System based on seven sets of information, relating to geology, soils, relief, erosion, vegetation, land use and climate. The information assembled was used to identify eight land classes, summarised in Table 2. The first four classes and possibly some of class V would be suitable for agroforestry. In general, intensive agriculture or horticulture would be a better use for land classes I–III, particularly when rainfall is adequate, the soil is moderately fertile and the site has adequate infrastructure and is near to markets.

Most of the land in western Viti Levu was originally forested. Land clearing, agricultural practices (including cropping on sloping land) and regular wildfire have led to degradation in

1 According to the Agriculture Minister of the Government of India, 'The country is facing various challenges such as rapid increase in human and cattle population, decreasing land–man ratio, widespread deforestation, excessive grazing, soil erosion, environmental deterioration, etc. The solution to combat these challenges lies in encouraging scientific agroforestry in non-forest lands' (Singh et al. 1995, Foreword).

2 While climate change mitigation in Africa has to date focused on reforestation and forest protection, Mbow et al. (2014) explained how agroforestry can contribute to climate change mitigation and adaptation while also providing livelihood benefits for farmers.

Table 1. Average monthly rainfall (mm) in Nadi and Lautoka, in Western Division of Fiji.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Nadi	299	302	324	163	78	62	46	58	77	103	138	159	1,809
Lautoka	298	303	322	170	86	70	47	60	85	98	143	186	1,868

Source: From Fiji Meterological Service records.

Table 2. Land use capability classification in Fiji.

Land use	Capability division	Major class	Slope
Arable	Suitable for ploughing and for intensive cropping	I–III	0–11°
	Unsuitable for ploughing but suitable for less intensive cropping under traditional cultivation methods	IV	12–15°
Non-arable	Unsuitable for arable cropping but suitable for pastoral or forestry use	V–VII	16–35°
	Unsuitable for productive vegetation; suitable only for protective purposes	VIII	35°+

Source: Adapted from Department of Agriculture, Fiji (nd).

land quality, although there is a substantial area suitable for forestry and agroforestry. Sugarcane fields are sometimes burnt before harvest, and fire is used for various other purposes. The spread of fire is aggravated by the presence of large areas of low-productivity grasses including mission grass (*Pennisetum polystachyon*) which fuel fires in the winter. Regular burning causes loss of organic matter, soil erosion, and deterioration in soil physical and chemical properties. Substantial effort and cost can be incurred in wildfire control.

TYPES OF DEGRADED LAND AND OBJECTIVES OF REHABILITATION

Reforestation of degraded land is a global issue. A literature search on land rehabilitation reveals that most of the attention is on restoring permanent vegetation. On land which has been used for cropping, establishment of some species of timber trees is relatively straightforward. Where land is severely degraded—such as where there is major loss of topsoil and gully formation, mine sites, desertification or chemical problems (saline, acid, alkaline, magnesium and sulphate)—special measures may be required for forestry establishment. There is a wealth of information available on rehabilitation of degraded areas—including watersheds, bare hills, mine sites and degraded coastal areas—but mostly for permanent revegetation rather than production forestry and agroforestry.

The focus of this paper is on improving the land suitability for establishing and subsequent maintenance of agroforestry on marginal cropping land, i.e. land with relatively low and seasonal rainfall which has been used for cropping or forestry. Relative to afforestation with monoculture timber species adapted to low rainfall and low soil fertility—for example eucalypts, acacias and teak—agroforestry systems which include fruit or nut trees and root crops, or combined crop and livestock production, generally require better soil conditions.

Literature on land degradation and land restoration more generally has been examined to gain a wider understanding of land rehabilitation problems and methods. Appendix A reviews various studies on rehabilitation of degraded land for forestry and agroforestry.

REHABILITATION OF MARGINAL AGROFORESTRY PLANTING SITES IN WESTERN VITI LEVU

A number of measures are possible for improving sites for planting mixtures of timber and fruit trees and food crops in western Viti Levu, where land degradation is not too severe. These are discussed below. However, improvement to planting sites by these methods may not be sufficient to ensure agroforestry establishment on degraded land, and more extensive land rehabilitation may be required.

Appendix A reviews lessons from reforestation studies which provide insights into agroforestry development.

Fallow agroforestry. This means essentially leaving an area for the natural vegetation to take over. Some enrichment planting may be carried out, e.g. of nitrogen-fixing tree or shrub species. Typically, the land is left for at least three years, and perhaps four or five years, allowing the soil organic matter content to build up. Fallow systems were used to achieve sustainable land use for thousands of years in Pacific island countries; when the human population was low, this type of shifting cultivation worked well. Nowadays there is greater pressure for short-term solutions to land rehabilitation, so alternative approaches are sought.

Enrichment of regenerating secondary forests with multipurpose species. A variation of the fallow agroforestry approach reported by Lamb (2011) and described in Appendix A concerns regeneration of secondary forests as a form of reforestation of degraded land. In some cases multipurpose species are used as enrichment plantings in these regenerating forests, to produce what are sometimes referred to as *agroforests* or *polyculture plantations*.

Green manure crops. As noted by Joy and Evans (2012) in a Hawaiian context, "There is much interest in growing plants for soil improvement and protection. Cover crops help keep soil in place, protecting it from raindrop impact, preventing surface sealing, and helping maintain its structure. Green manure crops incorporated into the soil add nutrients and organic matter, enhancing soil structure and nutrient availability, and supporting beneficial soil organisms." These authors list as examples the green manure legume species cowpea, lablab, pigeonpea, sunn hemp, white sweetclover and woollypod vetch.

Land ripping at planting sites. Soil compaction is a common type of land degradation on cropping land, and was noted by W. Unsworth (pers. comm. 2015) on land on which sugarcane had been planted and continued for three ratoon crops in Papua New Guinea. Growing sugarcane as repeated ratoon crops (sometimes for four to eight years before replanting) can result in considerable soil compaction. Mechanical ripping of the soil (e.g. cross ripping at planting sites), using machinery or draft animals or even labourers with hand tools, can undo soil compaction and increase water and root penetration. This can be particularly useful for growing root crops.

Planting hole design and nutrient improvement. Particularly for fruit trees, the focus may be on improvement in individual planting holes prior to planting. The size of holes is usually increased relative to those for forestry tree species, and compost or artificial fertiliser added. W. Unsworth (pers. comm. 2015) noted the addition of topsoil to planting holes for trees on sugarcane areas suffering from soil compaction in Papua New Guinea. In the context of agroforestry planting in the Philippines, Magraf and Milan (2004, p. 20) advised that "If the soil in your land is very poor, the hole to dig for the seedling should be bigger than on good soils and some compost should be added to give the seedling a good start." In the bare hills of northern Vietnam it was observed that wide-spaced large planting holes were dug for mango trees (a species highly favoured for timber as well as fruit in northern Vietnam), with prunings of *Acacia mangium* trees being progressively added as compost.

Nurse crops. The use of shade plants or nurse crops to improve the micro-environment—particularly to assist seedling establishment—is commonly recommended in agroforestry systems in Pacific island countries. These are often fast-growing species; examples include banana and pigeonpea.

Choosing species that can cope with difficult site conditions. On degraded sites it may be necessary to restrict the choice of species to those which can survive in difficult conditions with regard to soil moisture, soil structure and nutrient levels. For example, in western Viti Levu tree species which would survive low winter rainfall and low organic matter and nutrient levels (for example sandalwood, vesi, mango, cocoa) as well as hardy root crops (such as cassava, upland taro and kava) could be chosen.

CROP PROTECTION ON DEGRADED LAND

Agroforestry on degraded sites faces two major problems: establishment of trees and crops on sites which are degraded from previous land use and management (e.g. from deforestation, agricultural practices and wildfire), and risk of subsequent damage.

'Crop protection' includes protection from wildfire, cyclone, grazing livestock, and other pests (birds, insects) and diseases (viruses and fungi). Cyclone damage can be controlled to some extent by species choice for exposed sites. Pest and disease control is usually possible at a cost, and various minimisation measures are possible, e.g. exclusion of grazing animals, crop rotation and field sanitation. In general, agroforestry is likely to reduce the cost of cyclone damage and pest and disease damage relative to forestry or cropping alone.

Risk of fire is a major impediment to agroforestry in the drier areas of Viti Levu. Severe damage or total loss of agroforestry plantings due to wildfire obviously presents a huge discouragement to landholders to establish agroforestry. The focus of this section is limited to methods to protect agroforestry planting from fire damage.

As noted by Conservation International (CI 2013, pp. 57–58) in relation to their large agroforestry project in Ra province[3] in northern Viti Levu, "Historically, grassland fires in the project zone have occurred on an annual basis, largely due to pig hunting, careless behaviour, and stray fires from sugarcane burning. This could put the reforestation sites at risk, especially in the early years when the young trees are still establishing themselves."

Fires generate some social benefits for communities in western Viti Levu. Two major reasons for lighting fires concern sugarcane and pastures. Pre-harvest burning of sugarcane is carried out to remove leaves and make harvesting easier and to remove any biting or stinging wildlife.[4] Areas of mission grass with unpalatable mature leaves are burned to produce young shoots that are palatable to animals for a few weeks (King c. 2001). King identified 14 reasons why local people in Navosa province (near Nadi) light fires, including to clear walking tracks, to support growth and harvesting of wild food, and to help control wild animals as well as pests (slugs, snails, armyworm) and plant diseases.

Although use of fire has some community benefits, it seems that these are greatly exceeded by the costs incurred. Financial impacts include those arising from damage to infrastructure and associated repair costs, loss of crops or replanting costs, and cost of protection against or control of fires. Further, there is an opportunity cost in that more forestry and cropping would take place on what is currently underutilised land if the fire risk disincentive did not exist. The collections of research papers on fire effects on rural land edited by Cedrà and Robichaud (2009) and Paton et al. (2014) reveal the severe impact fire can have on rural land in terms of loss of organic matter, surface and gully erosion, and degradation of soil structure and chemical composition. These environmental impacts impose costs in the form of loss of production and of land restoration. Other environmental impacts include microclimate effect of loss of vegetation, air pollution particles from fires, and release of CO_2 into the atmosphere (although sugarcane growing and pre-harvest burning would have an approximately neutral carbon balance).

Physical fire prevention methods

As noted above, wildfires are frequent in western Viti Levu, and effective fire prevention would greatly improve the prospects for agroforestry adoption by landholders. Hence there is a need to eliminate fire risk, or at least reduce this risk to a level where landholders can control fires. Various strategies could be adopted to help eliminate or reduce the risk of fire damage—or at least reduce the extent of damage—some of which are now reviewed.

Firebreaks versus shaded fuelbreaks

Fitzgerald (nd) noted the distinction between firebreaks and shaded fuelbreaks. He defined the former as "an area where all vegetation and organic matter is removed down to mineral soil, thereby removing the fuel leg of the fire triangle". This was contrasted with a shaded fuelbreak, "a strip of land where fuel (for example, living trees and brush, and dead branches, needles, or downed logs) has been

3 The Western Division of Viti Levu consists of three of Fiji's 14 provinces, namely Ba in the north-west, Nadroga-Navosa (south-west and central areas) and Ra (in the north), as well as some offshore islands.

4 Unlike in the Australian sugar industry, venomous snakes do not appear to be present in Fiji sugarcane plantations.

modified or reduced to limit the fire's ability to spread rapidly". Fitzgerald suggested that firebreaks be surfaced with crushed rock, which would prevent erosion and weed growth. The context of these definitions was the protection of homes and property in Oregon, western USA, where conifers are the main tree species. Hard surfacing probably would not be financially feasible in a Pacific island smallholder setting. Also, the rainfall is somewhat higher, and more fire-resistant species could be used in fuelbreaks. However, Fitzgerald has provided some useful information on designing shaded fuelbreaks, which would be relevant for western Viti Levu. Some major points include the following.

- Fires can burn through the fuelbreak, although at reduced intensity and rate of spread, such that firefighting becomes easier.
- Shaded fuelbreaks are less costly to construct than firebreaks on a per area basis, but need to be much wider.
- Fuelbreaks are often placed above and below existing roads or adjacent to wet areas and rocky outcrops.
- Required vegetative stand width increases as slope increases.
- In low rainfall areas and on steep slopes, fuelbreak width may need to be 200 feet (about 60 m) or more.
- Tree spacing may be wider at the lower edge of the stand than the rest of the stand.
- Within the shaded fuelbreak overstorey trees may need to be thinned to reduce crown-to-crown overlap; sale of merchantable thinnings can offset costs.
- Other periodic maintenance of fuelbreaks may be required.

Firebreaks in northern Thailand

Elliot et al. (2004, p. 4) carried out research into forest restoration in a sugar-growing area near Chiang Mai in northern Thailand. It was noted that "Compared with soil in undisturbed evergreen forest at a similar elevation, soil in the study site before planting was significantly more acidic and contained significantly less organic matter and nitrogen, more sand and less silt and clay, which is the result of forest degradation and fire." Elliot et al. (2004, p. 5) further commented that "Fire prevention measures, including cutting firebreaks around the plots and employment of a team of villagers to act as firewatchers, were initiated at the beginning of January each year and continued until April or May, depending on the arrival of the first rains." Lamb (2011, p. 181) described how a community in northern Thailand successfully converted a grassland area dominated by *Imperata cyclindrica* into a village forest. This was achieved by establishing firebreaks around the selected area, after which "Each year every household was required to contribute labour to build and maintain the firebreak … Over time natural regeneration began to appear …".

Fuelbreaks using tree species

From various discussions, the establishment of forest fuelbreaks seems to offer promise in western Viti Levu. These may require the use of exotic rather than Pacific island tree species. In that wildfire moves most rapidly on sloping land, and generally moves in an uphill direction, green belts would be preferably placed on lower slopes and below agroforestry plantings. It is envisaged that they would take the form of long narrow strips planted on the contour.

Establishing a eucalypt fuelbreak

D. Lamb (pers. comm. 2015) was presented with photographs of degraded sugarcane land in western Viti Levu and asked to suggest—based on extensive experience in reforestation—how he would recommend fire control be managed on individually owned properties in this area. One suggestion was to develop green strips of a thick-barked fire-resistant eucalypt species downhill from agroforestry plantings, and to run fuel-reduction cool fires through these annually at the beginning of the dry season. A potential would exist for harvesting some timber poles—a high-value timber product—from the site. Notably, Lamb took the view that the sites depicted in the photographs should not pose major problems for tree planting and establishment.

Further email correspondence with Dr Lamb and forester Paul Ryan elaborated on fuel reduction breaks. It was suggested that a series of rows of a fire-resistant tree species could be established across the downhill side of an agroforestry planting. A necessary step would be to identify what characteristics the tree species should possess to be a suitable fuelbreak, and which species possess these characteristics. Tolerance of poor sites, rapid growth, limited ground litter, low ability to carry a canopy fire, ability to recover after a fire, and production of useful timber would all be useful properties.

Spotted gum (*Corymbia citriodora* subsp. *variegata* and subsp. *citriodora*) was identified as an obvious candidate.[5] It is capable of rapid growth, even on relatively poor sites, is tolerant of fire and is a recognised commercial species. Spotted gum has a relatively sparse and non-flammable canopy, and is unlikely to carry a crown fire. Trees could be planted in say six rows across the contour, with tree spacing of say 5 m within and between rows. Some grass control may be needed at the time of planting, e.g. spraying out flammable shrub and grass species with glyphosate. An annual controlled burn of the grass and other undergrowth in the fuelbreak at the beginning of the dry season and before the commencement of sugarcane harvesting (about May) was envisaged.

The quicker a break can be established between ground and crown the better, so branch pruning should be carried out. However, this does in turn create a problem of increased ground fuel load, temporarily at least, and may require creative thinking to come up with a solution to mitigate the risk (e.g. use of prunings for organic fertiliser in timber or fruit tree planting sites). While annual burning would reduce the intensity of a fire, it may still be necessary for the landholders to have the capacity to occasionally control a running ground fire. As the trees gain height, some thinning may be desirable. Spotted gum trunks make ideal power poles.

Eucalyptus camaldulensis and *E. tereticornis* could also be considered for fuelbreaks. However, these species have the disadvantage of being flammable (due to their leaf oils and their litter makeup and configuration) so even with yearly prescribed burning, stands possibly could carry fire at critical times. *E. resinifera* and *E. pellita* are not flammable to the same degree and carry deeper, denser crowns but prefer somewhat better soils, while *E. pellita* in particular is susceptible to wind damage.

Using acacia species for fuelbreaks

An alternative to a burnt buffer strip is a fire retardant or suppressant unburnt strip. A number of acacia species may be suitable for this purpose, including commercially useful species (e.g. *Acacia mangium* and *A. auriculiformis*) or others which may be useful but not necessarily commercially. The key factors are that they would not carry a crown fire and that any ground fire would be relatively slow and easily controlled. This depends in part on the environment in which the agroforestry is being established.

Acacia aulacocarpa, *A. auriculiformis*, *A. crassicarpa* and *A. mangium* are all grown in commercial plantations to a greater or lesser degree (primarily for pulp) and could be considered. It is likely that these species would be less inclined to carry a running fire than eucalypts but would be more susceptible to damage from the same intensity of fire. *A. crassicarpa* and *A. mangium* are particularly susceptible to wind damage which could dramatically increase fuel load and the difficulty of access and fire management.

Another less well known acacia species which might be effective in a fire retardant or suppressant strip is *A. hylonoma*. This species, which occurs in rainforests in north Queensland, grows to a height of about 20 m and dbh of about 20 cm. It has performed well in ACIAR trials on poor soils but with fertiliser in southern Queensland. It is generally multi-stemmed from near ground level, carries a dense crown with no understory and produces a flat litter layer. More information is needed about the response of this species to fire.

Other tree species as candidates for fuelbreaks

Teak (*Tectona grandis*) and mahogany (*Swietenia* spp.), which are currently grown as plantation species in western Viti Levu, may also be options for fuelbreaks. Teak is more tolerant of difficult sites and relatively low rainfall than mahogany. As a deciduous tree, teak does create a litter of flammable material on the soil surface, as well as providing less protection from soil erosion during part of the year. Observations in

5 According to ANPSA (nd), "The three genera *Eucalyptus*, *Corymbia* and *Angophora* are known collectively as 'eucalypts'. With over 700 species, the eucalypt dominates many Australian landscapes …".

Fiji suggest some of the teak planted is of low genetic quality, with fluting of trunks reducing timber value, though it should be possible to obtain improved germplasm.

Grazed native and improved pastures as fuelbreaks

Silvopastoral systems, such as fenced 'cattle under coconuts', or opportunistic grazing on improved or native pastures or agroforestry stands (e.g. sandalwood and leucaena for tethered cattle or goats), appear to warrant investigation for fire management. Grazing systems have the advantage of being less labour intensive than crops, and are in general favoured on sloping land where rainfall is sufficient for year-round pasture growth. Appendix B discusses research into pastures in Vanuatu and Fiji, including choice of grass and legume species.

Low quality grasses including mission grass—which is highly flammable for much of the year—could be replaced by buffalo grass, an evergreen species widely used in coconut plantations in Vanuatu (and for lawns in Australia). Trials of this species by the authors in an agroforestry setting in south-east Queensland reveal that it can be established using (and spreads rapidly by) runners, in areas with a similar rainfall pattern to western Viti Levu. The new growth of mission grass (perhaps after some grazing) could be sprayed out with glyphosate, and then the buffalo grass introduced.

Vetiver grass hedges as fuelbreaks

Another grass fuelbreak option is the planting of lines of vetiver grass (*Vetiveria zizanioides* L.), a species usually grown for soil protection rather than grazing, including in sugarcane-growing areas in Fiji. According to Truong and Gawander (c. 1994), "In all sugar cane growing areas, from the low slope fields around Lautoka to very steep hillsides around Rakiraki, terraces formed by Vetiver hedges up to 1.5 m high are quite common. These terraces were formed by soil erosion upslope and subsequent trapping by Vetiver hedges downslope over a 25–40 year period. The spacings between hedges are relatively close (averaging 30–40 m apart)."

This tall grass species has a number of important features. According to Truong (2000), these include "a massive and deep root system, tolerance to extreme climatic variations such as prolonged drought, flood, submergence, fire, frost and heat waves. It is also tolerant to a wide range of soil acidity, alkalinity, salinity, sodicity, agrochemicals and elevated levels of heavy metals in the soil." Truong (2000) further noted that "Even in a very dry state vetiver top does not burn readily and remains green during summer so vetiver is being used in South Africa as a fire barrier protecting forest plantation from creeping grass fire." The view that vetiver has potential for wildfire control is supported by Vetiver Systems Hawaii LLC (2008), which reported that "Green vetiver hedges are very dense, and fire has difficulty penetrating them. Under these conditions, the hedge acts as a fire break to slow creeping fires. Where Vetiver in Fiji was grown in conjunction with sugar cane it survived the annual fire that was set before the cane harvest."

The drought tolerance and evergreen foliage of vetiver grass, as well as the physical barrier it can create by sediment trapping, make it a serious possibility for use as (or within) firebreaks. This species has a number of other attractive features. At a recent conference in Da Nang, Vietnam, it was reported that "Over 40 provinces and cities have been planting vetiver grass to mitigate a spate of environmental problems … the grass helps deal with water and soil pollution, desertification, climate change and disaster mitigation as well as prevention of erosion and stabilising river banks and sea dykes" and also that "Vetiver-made textile products and souvenirs were displayed" (Anon. 2015).

Food gardens as firebreaks

A practice used in the Philippines to prevent fires in forestry and agroforestry areas is for communities (people's organisations) to establish firebreaks of about 10 m width and to maintain these permanently throughout the year (N.O. Gregorio pers. comm. 2015). In some cases these areas are kept clear of vegetation, while in other cases they become strips of fire-resistant food crops, including pineapple, sweetpotato and cassava. An added advantage of the crops is that they reduce soil loss on the sloping land. Beaters made from several thicknesses of coconut palm leaves are used to extinguish any fire outbreaks.

Using multiple approaches to fire control—the Conservation International approach

Conservation International (CI 2013) described a major program of planting teak, mahogany and about 30 traditional Pacific island tree species in Ra province in northern Viti Levu (an area with a slightly higher rainfall than Ba province further to the west). The concern about wildfire is evident in the CI (2013) report, which has a total of 88 incidences of the word 'fire'. The areas planned for reforestation in the CI project "are located on the degraded talasiga grasslands that cover the lower elevations and slopes of the Nakauvadra range" (CI 2013, p. 5). The term *talasiga* means 'sun burnt land', i.e. fire-modified and fire-degraded land, in Fijian. Establishment of native tree species on these grasslands and fernlands has been prevented by occasional fires and low soil fertility.

Firebreaks have been established around the reforestation sites following guidelines developed by Fiji Pine Limited. Fire-retardant food crops—including pineapple, coconut and citrus—are grown, and provide an incentive for the community to protect planted areas. Community fire wardens have been hired and trained, and patrol the project areas, reporting any fire instances to the CI field office and Fire Authority. They provide quarterly reports to the environment officer in the provincial council for presentation at tikina and provincial council meetings.

Fire prevention awareness campaigns are a key component of the project. According to CI (2013, p. 43), "CI has carried out annual fire awareness and information meetings since 2009, in conjunction with the Methodist Church, the Fire Authority and Divisional Police Force." Annual fire prevention and educational campaigns at village and tikina meetings have been held in partnership with the district committee and Methodist church. The national Fire Authority and Police Department of Rakiraki are also invited to attend and to inform communities on the legal implications of starting fires in accordance with the 2009 Crimes Decree. The threat of fire to human health and safety, and the negative impacts on soil erosion and runoff, have been stressed at district and provincial council meetings. There has been a reduction in the occurrence of fire, although protecting forest sites adjacent to sugarcane plantations which are burned during harvesting remains a challenge.

Institutional approaches to control of wildfire

While physical activities are critical in wildfire management and land rehabilitation, there are also 'social' issues—policy, legislation and regulations, land tenure and general governance issues—that may be critical to successful wildfire management. Lighting fires is entrenched and to some extent socially acceptable behaviour in western Viti Levu. Further, regular fires are viewed to some extent as a fuel-reduction measure, to prevent large uncontrollable fires which may endanger human life.

It is possible that the frequency of fires would be reduced if the sugar industry reduced the prevalence of pre-harvest burning. Reddy (c. 2003) reported that the proportion of total sugarcane supplied as burnt for crushing in Fiji increased from 14.8% during 1971–1975 to 45.5% in 1996–2000. This was not due so much to greater ease of harvesting as to haste to get the sugarcane to the mill before the annual crushing season ceased, in part due to a shortage of sugarcane cutters. More recently, a move to green harvesting has been promoted. Chaudhary (2011) reported that "There have been a few instances of indiscriminate burning and we urge growers to please send fresh green cane." Chaudhary further noted the lack of uniformity in supply rates of sugarcane for milling associated with a shortage of cane cutting labour, extending the cutting period into the wet season, commenting that "due to the fact that the majority of cutters are iTaukei, there is very little harvesting done over the weekend because of religious obligations and social activities."

A movement to green cane trash blanketing—leaving harvest residue on the land surface—has environmental benefits and leads to higher cane quality, but would require greater use of mechanical harvesters. Macfarlane (2009, p. 9) observed that with the movement from burnt to green cane harvesting, more trash would need to be ploughed into the soil or fed to livestock, which has both costs and benefits.

Reddy (c. 2003) reported a fall in the proportion of sugarcane area newly planted in Fiji, from about 25% in the 1960s and 1970s to less than 10% during the period 1996 to 2001. He attributed the increase in the number of ratoon crops to insecurity of land tenure, just under 50% of expired 30-year sugarcane leases being renewed in 2000 and 2001. Long rotations lead to soil compaction (W. Unsworth pers. comm. 2015) and sugarcane yield decreases from one ratoon crop to the next (Reddy c. 2003).

A number of policy approaches are available to reduce the incidence of wildfire. Perhaps the most effective would be a campaign to make the public (rural and urban, and including canegrowers) more aware of the damage to crops and land caused by uncontrolled fires. Another measure would be appointment of fire wardens and scouts, as adopted by the CI project in Ra province. CI (2013, pp. 101–102) noted that their project "is carrying out fire awareness and educational campaigns with local communities and surveillance patrols with fire wardens, and will continue its efforts to propose preventative methods for fire with the sugarcane farmers." Also, with the dramatic fall in the cost and increase in the use of miniature unmanned aircraft (drone) technology, including for forestry surveillance, it should be possible to increase the cost-effectiveness of monitoring fire outbreaks.[6]

Any measures of moral suasion and vigilance would need to be backed by strong legal enforcement to discourage fire lighting in the dry season (approximately June to August). While legislation already exists in Fiji to seek financial compensation for fire damages, costs are incurred in seeking restitution, and the outcome can be uncertain in a community in which fire events are frequent and in general tolerated.

SUGGESTIONS FOR FURTHER RESEARCH

The policies and practices discussed in this working paper have been assembled from various sources, including extensive literature review on experiences at other locations, and discussions with forest management and policy experts, but further evaluation is required to gauge the effectiveness of alternative control measures.

Further investigation is needed to provide greater confidence in deciding what land rehabilitation measures would be most successful. Establishment of trials and demonstration sites on land improvement and agroforestry establishment in western Viti Levu would both add to scientific knowledge and increase the interest of landholders in agroforestry adoption. Trials could be conducted on the effectiveness of firebreaks, fuel reduction with forestry, and grazed improved pastures and vetiver barriers. Such trials could be conducted in locations readily accessible to researchers and visitors, where fire has been a persistent problem. It would be useful to keep financial records of establishment of fuel reduction barriers, so that their cost-effectiveness can be assessed.

A further suggestion is that trials be conducted on establishment of agroforestry plantings on degraded areas to compare the performance of mechanical treatment of planting sites and use of topsoil, composting and artificial fertilisers.

CONCLUDING COMMENTS

Mixed species agroforestry systems have much to offer from a rural development perspective. An examination of reforestation and agroforestation measures in tropical countries reveals that various measures are available to improve agroforestry establishment on degraded land including relatively low rainfall sites such as in western Viti Levu in Fiji. Occurrence of regular uncontrolled fires presents a major impediment to agroforestry expansion, from a technical and psychological perspective. Various

6 Blankenbuehler (2015) described a group from the University of Missouri training firefighters in the Santa Rosa National Park in Costa Rica to integrate drone technology into their fire management strategies. It is noted that fires "pose a constant threat to the dry tropical forest" and that "almost all [the] fires are caused by human activity: ranching and agricultural practices, but also arson against the park or individuals residing near the boundaries". An average of 22 fires per dry season is estimated. Four remote-controlled drones were acquired, which transmit photo information to smartphones. Some applications identified include "monitoring direction and speeds of advancing fires, establishing safety points, assisting with geographic information system mapping, tracking down illegal logging, illegal cattle grazing and even locations of illegal marijuana plantations" as well as replacing use of expensive helicopters. The potential for saving lives of firefighters through finding safe exit paths was noted.

measures to reduce wildfire incidence are available. Field trials and demonstration sites would improve understanding of agroforestry establishment and crop protection, and potentially increase agroforestry adoption on difficult sites.

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APPENDIX A. SOME EXAMPLES OF REFORESTATION ON DEGRADED LAND

An extensive literature exists on reforestation of degraded land, such as watersheds (river catchment areas), deforested and degraded hill country, mining sites and even desert areas. Typically, the objective is land rehabilitation for conservation purposes, although there is often provision for some harvesting of timber or other products. While this literature in general deals with establishing monoculture or mixed-species trees (with less demanding site requirements than agroforestry systems) or more degraded sites than in western Viti Levu, these reforestation studies provide some valuable insights relevant to the ACIAR agroforestry research in Fiji. Some of the reforestation studies are reported below. The studies are presented in approximately chronological order. The intention is not to provide comprehensive descriptions but to highlight features which are relevant to agroforestry development in Fiji and Vanuatu. While some of the studies have relevance for clean development mechanism projects, which can include afforestation and reforestation activities, this aspect is not discussed.

These studies provide valuable insights into establishment of agroforestry on degraded land. Often the reforestation efforts are designed to restore permanent vegetation, although some harvesting may be achieved. The selected information drawn from these studies suggests that reforestation is successful on most situations of degraded land in the tropics, through natural or assisted regeneration or through reforestation activities, though this can be difficult when fire is frequent, soil organic matter is lost, and soil physical and chemical properties are altered. Mining sites provide particular difficulty, and rehabilitation to a productive state may not be a viable proposition.

US Office of Technical Assistance and Technology (OTA) 1983 study

OTA (1983, pp. 8–9), in a background paper on reforestation of degraded land, noted the benefits of planting trees "because of their ability to use water and nutrients inaccessible to plants with shallow roots and because they supply a multitude of products: wood, fuel, fodder, and others. ... a tree canopy acts as a buffer against the direct impact of raindrops on the soil. The litter and humus layers underlying the forest absorb moisture, allowing water to infiltrate the ground and recharge the ground water supply ... Trees, by shading the soil, reduce soil temperatures and thus promote accumulation of organic matter and retard possible soil hardening." They further noted that soil organic matter contributes to the development of soil aggregates, enhances root development, reduces the energy needed to work the soil, increases air- and water-holding capacity of the soil, reduces erosion, releases essential plant nutrients, holds nutrients from fertiliser in storage until the plants need them, and supports soil biota.

Large-scale long-term land restoration projects in China

Zhaohua (1995) reported on various large-scale forestry and agroforestry planting initiatives in China. Two notable systems were the Three Norths Shelterbelt Program or 'Green Great Wall' and Four Sides Planting Program. The former had an area target of 4.7 million km² (42.7% of China's land area), to be planted over 1978 to 2050, covering a region "of strong sandstorms … and serious water and soil erosion" (p. 72). The program included protection of existing vegetation and new production and protection forestry, within a network of shelterbelts. The latter program included planting around houses, villages, roads and watercourses; at the time of writing 7.2 billion trees had been planted in this program. Zhaohua also reported major intercropping activities in the northern plains and hill and mountain areas. These projects—including reforestation on desert areas—are continuing.

Rehabilitation of degraded forest ecosystems in Asia—policy issues

Gilmour et al. (2000) produced a report on rehabilitation of degraded forest ecosystems with particular reference to Cambodia, Laos, Thailand and Vietnam. A notable feature of this report was the examination of evolution of forest policies and of blockages to progress, and a forward-looking assessment of policy requirements. For example, it is argued (p. 21) that "One of the big challenges for the future is to develop policy and practical approaches to achieving ecologically sustainable forest management by integrating economic, social and environmental values into forest management. In the majority of cases, economic considerations dominate decision-making. This has given rise to the situation where activities such as forest rehabilitation (generally through plantation establishment) are driven by economic arguments, and ecological values are addressed by establishing protected areas. … An effective way of addressing the ecological and social objectives of forest management is to carry out land use planning on a landscape scale and involve a wide range of stakeholders in the debate." The report also identifies technical constraints to rehabilitation progress, relating to site–species matching, quality of seeds and seedlings, techniques for low-cost natural regeneration, standard of post-establishment silviculture (particularly tending and protection), and locally appropriate and sustainable harvesting systems.

ITTO guidelines for the restoration of degraded and secondary tropical forests

The International Tropical Timber Organization (ITTO 2002, Foreword) commented that "some 350 million hectares of tropical forest land have been so severely damaged that forests won't grow back spontaneously, while a further 500 million hectares have forest cover that is either degraded or has regrown after initial deforestation. … Such large areas of damaged forest and land are cause for concern, but they also represent a potential resource of immense value. *The ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary forests* have been formulated to help communities realize that potential. … Forests can serve many functions at the local, landscape, national and global levels, but only if they are in good health. They can provide local communities with sustainable supplies of clean water, timber, fuelwood and other products and services, and they can contribute to the global quest to conserve biodiversity and reduce atmospheric carbon. Restoring, rehabilitating, managing and protecting forests for such functions are undeniably important tasks." In developing their guidelines, ITTO worked with many institutions, in particular the Center for International Forestry Research (CIFOR), the Food and Agricuture Organization of the UN (FAO), the International Union for Conervation of Nature (IUCN) and the World Wide Fund for Nature (WWF International).

ITTO (2002, p. 10) provided a number of definitions in relation to degraded forests in tropical landscapes:

"• *degraded primary forest*: in which the initial cover has been adversely affected by unsustainable harvesting so that its structure, processes, functions and dynamics are altered beyond the short-term resilience of the ecosystem;

- *secondary forest*: woody vegetation regrowing on land that was largely cleared of its original forest cover. Secondary forests commonly develop naturally on land abandoned after shifting cultivation, settled agriculture, pasture, or failed tree plantations;
- *degraded forest land*: former forest land severely damaged by the excessive harvesting of timber and other forest products, poor management, repeated fire, grazing or other disturbances or land-uses that damage soil and vegetation to a degree that inhibits or severely delays the re-establishment of forest after abandonment."

The authors also addressed the policy, legal and institutional framework of restoration of degraded forests (p. 20 et seq.).

'Site-level' rehabilitation and restoration of degraded forests

Lamb and Gilmour (2003, Ch. 6) described a number of methods for 'site level' rehabilitation and restoration of degraded forests, including: passive restoration (site protection); enrichment planting (reintroduction of key species); direct seeding (by hand or air, usually on bare soil); scattered tree plantings (planting small numbers of scattered or clumped trees, or rows of trees); close-spaced plantings (the 'framework species method'); intensive ecological reconstruction (dense planting of many species); and intensive ecological reconstruction after mining. They noted, in relation to the last of these cases, that "Some mining companies have opted for forms of reclamation using exotic species (e.g. pastures for grazing or exotic tree plantations), believing restoration to be too difficult. … Conditions limiting plant growth, such as low levels of topsoil fertility or poor soil physical conditions, also need to be identified and dealt with by fertilisers, ripping etc. Once mining is complete it is necessary to reconfigure the topography of the site to minimize wind or water erosion and re-establish drainage lines. Revegetation after mining can be done by planting seedlings or by direct seeding …" (Lamb and Gilmour 2003, pp. 40–41).

Rainforest re-establishment in northern Thailand

Elliot et al. (2004) described experiments by the Forest Restoration Research Unit (FORRU), Chiang Mai University with the framework species method—which they attribute to Goosem and Tucker (1995)—for re-establishing rainforest in a degraded watershed in a national park in northern Thailand. This method uses "30 indigenous forest tree species, carefully selected for their ability to accelerate natural forest regeneration. The hypothesis is that planted trees should restore forest structure and ecological functioning, whilst wildlife attracted by the planted trees accelerate biodiversity recovery through seed dispersal, resulting in recruitment of non-planted tree species." A later paper by Elliot and Kuaraksa (2008) reports on the extensive research conducted by FORRU in collecting and germinating seed of hundreds of tree species, and progress in rainforest re-establishment in the park.

Research into the growing of rainforest tree species in tropical north Queensland, Australia

Tropical north Queensland (the Cairns hinterland) is well known for the large number of high quality 'cabinet timber' tree species, and had a thriving timber industry until the highly controversial listing of the Wet Tropics of Queensland World Heritage Area in 1998, covering about 8,940 km^2. This led to the contraction from 40 sawmills in the region to only three. Subsequently, the Community Rainforest Reforestation Program (CRRP, 1993–2000) was established in north Queensland to promote and financially support tree planting on private land, with an aim of re-establishing the timber industry and providing watershed protection. A list of about 150 native tree species, few of which had been grown commercially but many of which have timber with excellent wood properties, was initially developed for CRRP planting. The Cooperative Research Centre for Tropical Rainforest Ecology and Management (CRC-TREM) was also established in 1993 as a joint venture between the Australian Commonwealth Government, Queensland State Government and a number of local government authorities in the region. Later known as the Rainforest CRC, this agency operated for about 12 years, and much of its research activity was focussed on CRRP plantings.

Erskine et al. (2005) produced a major report for the Australian Rural Industries Research and Development Corporation (RIRDC) on the achievements of the Rainforest CRC. Among the many findings in relation to reforestation were the following observations.

- Expert opinion indicated that individual tree species had widely differing rotation lengths, from about 30 to 80 years.
- Planting took place on both the coastal flats and the tableland area (both of which are also used for sugarcane growing).
- No major problems were experienced—and shade trees were not needed—with tree establishment.
- Most of the tree planting was of multiple species, and over time a system was developed in which whole rows of particular species were planted rather than more intimate mixtures (simplifying silviculture and potentially making harvesting simpler).
- The list of species planted narrowed down over time, to about 20 which demonstrated sound early growth performance.
- Some positive and some negative interactions between species were identifiable.
- The rate of uptake of the CRRP program by landholders was disappointingly low, although subsequent planting of rainforest tree species outside the program was unexpectedly high.

Tropical reforestation in the Asia-Pacific region

Lamb's publication (2011) on 'regreening the bare hills' provides case studies of land degradation and reforestation in seven countries: Malaysia (Sarawak), the Philippines, Thailand, Australia (north Queensland), Indonesia (Kalimantan), Papua New Guinea (Gogol Valley) and Western Samoa. Lamb (2011, p. 185 et seq.) observed that natural regeneration of secondary forests can sometimes succeed on degraded land, but success is less certain on "a grassland site with only a few scattered woody plants". Lamb (2011, p. 196) made the point that enrichment planting in secondary forests using food species and other non-timber forest product species is sometimes undertaken to "provide households with a wider range of products and an earlier supply of these than unmodified secondary forests … [and] also provide significant cash incomes. … These cultivated forests have been referred to as 'agroforests', 'improved fallows', 'polyculture plantations' or 'forest gardens' and a variety of different types are found throughout the Asia-Pacific region." In other words, one method of establishing agroforestry systems is through enrichment of regenerating secondary forests with multipurpose tree species.

Restoration of fire-damaged forest areas

The collections of papers edited by Cedrà and Robichaud (2009) and Paton et al. (2014) describe in detail the various negative impacts of wildfire on rural land, and provide suggestions about measures which may be adopted to restore land degraded as a result of fire. Adverse impacts include loss of soil organic matter, soil compaction, severe soil erosion and gullying, and major changes in the chemical composition of surface soil. Tree and grass planting are among the restoration measures. Mechanical measures including gully blocks may be used in the treatment of gully erosion. An approach of using natural mulch (conifer needle cast) for immediate ground cover, as well as natural recovery, is described by Robichaud (2009).

Use of nitrogen-fixing tree species in land rehabilitation

Nair (1993, Ch. 17) and Atangana et al. (2014, Ch. 8) discussed the role of nitrogen-fixing agroforestry tree species in improving land condition in the tropics. Low nitrogen content is a common problem in degraded land, and biological nitrogen fixation can be an inexpensive way of remedying this deficiency. Most legume species fix nitrogen through root nodules, some examples relevant to agroforestry being *Acacia* spp., *Leucaena leucocephala*, *Sesbania grandiflora*, *Gliricidia sepium*, *Pongamia pinnata*, *Erythrina indica*, *Albizia lebbeck* and *A. falcataria* (recently renamed *Paraserianthes falcataria*). According to Atangana et al. (2014, pp. 186–187), "About 200 non-legume plants, in 24 genera belonging to the Betulaceae, Casuarinaceae, Coriaceae, Cycadaceae, Eleagnaceae, Myriaceae, Rhamnaceae, Rosaceae, and Ulmaceae families form symbiotic associations with [the bacteria genus] *Frankia*." A notable non-leguminous nitrogen-fixing tree species used in Pacific island agroforestry in *Casuarina equisetifolia*. Some nitrogen-fixing tree species also form symbiotic associations with mycorrhizal fungi, which often enhances nutrient uptake and increases nitrogen fixation ability.

Restoration of coal mining sites in the Bowen Basin, Queensland

Erskine and Fletcher (2013) reviewed mining site rehabilitation in the Bowen Basin of Queensland, an Australian state with heavy financial dependence on the mining industry. Beef cattle raising has traditionally been the main rural land use in this region. However, open-cut coal mining has also taken place in the region for about 50 years, and mine rehabilitators have used various tree, shrub, and groundcover species "to stabilise soils and provide vegetative cover for pre-supposed final end-landuses" (Erskine and Fletcher 2013, p. 1). These authors compared slopes, soil chemistry, and plant species mixes with those of selected reference communities. Mines in this region have generally proposed one of two post-rehabilitation end-landuses: either pasture for cattle grazing or reconstructed native communities which potentially provide native fauna habitat. Much of the rehabilitation is currently dominated by exotic buffel grass (*Cenchrus ciliaris*)—a highly favoured exotic pasture species—and *Acacia* species. The authors noted that "Landform data from a selection of these mine sites suggest that when their rehabilitation was compared to nearby reference sites median slope values were between 2.5 and 7 times steeper and soil pH, electrical conductivity, and phosphorus levels were significantly higher", highlighting the difficulty in rehabilitating these sites.

Reforestation of degraded sugarcane land in Papua New Guinea

W. Unsworth (pers. comm. 2015) noted the combined use of fuel reduction and hired scouts for the monitoring of fire in new plantings of *Acacia mangium* and *Eucalyptus pellita* on what was previously sugarcane land in the Ramu river valley in Papua New Guinea. Fuel reduction consisted of mechanical weed control of young tree seedlings, and spraying with glyphosate (Roundup) for larger seedlings. Fire surveillance involved hiring villagers as fire scouts at the beginning of the dry season (about April) through to the beginning of the rainy season, to raise alerts on any fire incidents. People were rotated in this (unexciting) job, and were dependent on each other to ensure fire prevention so that the employment would continue.

APPENDIX B. PASTURE GRASS AND LEGUME SPECIES IN FIJI AND VANUATU

Establishment of silvopastoral systems as fuelbreaks to eliminate or greatly reduce wildfire involves choice of grass and legume species suited to particular sites. Silvopastoral systems may be established to replace existing low-quality grasses, for example on the 'brown lands' in western Viti Levu in Fiji. Considerable research has been conducted into appropriate grass and legume species in Fiji and Vanuatu.

According to Twyford and Wright (1965, as reported by Manueli nd) in relation to pasture improvement, the climate of Fiji is classified into three categories, namely wet, intermediate and dry. Manueli (nd) further noted that "The dry climate occurs in the rainshadow areas of the high islands and is characterised by a distinct dry season (June–November) each year, an average annual rainfall of 1,400–2,500 mm and mean annual temperature of 25.5°C."

Manueli (nd) further commented in relation to pastures in Fiji that "Dry Zone Pastures are characterised by a predominance of Mission (*Penniseteum polystachon*) and Nadi Blue (*Dicanthium caricosum*) grasses … levels of legumes in the pasture are generally low, … characterised by a low annual dry matter production and marked seasonal variation in the production of dry matter and pasture quality. The problem is further exacerbated by the high levels of weed infestation in the majority of pastures. In the DZP, legumes of the genus *Desmodium* are generally well distributed throughout the sward; however limitations of soil fertility (primarily P, K & S) result in low productivity of *Desmodium* in comparison with improved legume species currently in use in other countries. Commonly occurring weeds include Drala (*Vitex triflora*), Guava (*Psidium guajava*), Mile a minute (*Mikania micrantha*), Crotolaria (*Crotalaria aciculatus*) and Tobacco weed (*Elephantopus scaber*) …."

Macfarlane (2009, p. 9) in a report on forage resources in Fiji commented that "Overgrazing and uncontrolled fire reduce production through weed invasion or causing species shifts to less palatable and lower quality grasses. Wide boundary strips of low growing, drought tolerant and fairly evergreen pasture plants could restrict fires that are often lit for hunting. Regular burning contributes to N and S losses from grazing systems whereas planned and timely fire is an important tool in converting natural to improved pastures and in controlling woody weeds." Macfarlane further commented (p. 10) that "The national cattle herd grazes 125 000 ha of unimproved *Pennisetum polystachyon* (Mission grass), 43 000 ha of naturalised/ native pastures including *Dicanthium caricosum* (Nadi blue), *Ischaemum indicum* (Batiki), *Axonopus compressus* (carpet), *Paspalum conjugatum* (T-grass) and an unquantified area of roadsides and recently harvested cane fields. There is a further 175 000 ha of ungrazed *Pennisetum polystachyion*."

Mission grass grows to a height of over 1 m and up to about 3 m, has low grazing value except for new growth, and carries fire in the dry season. According to the Northern Territory Department of Land Resource Management (nd), "Perennial mission grass is declared a Class B (spread to be controlled) and Class C (not to be introduced to the Northern Territory) weed in accordance with the *Weeds Management Act 2001*." Similarly, Plantwise Knowledge Bank (nd) reported that mission grass "is listed as a Federal Noxious Weed in USA".

In Vanuatu, a major research project—the Vanuatu Pasture Improvement Project—has been conducted to improve the productivity of pastures (Government of Vanuatu and AIDAB nd). The report describes various grass and legume species with potential for improvement or use in Vanuatu. A few of the grass species trialled include koronivia grass (*Brachiaria humidicola* cv. Tully), buffalo grass (*Stenotaphrum secundatum*), signal grass (*Brachiaria decumbens* cv. Basilisk) and buffel grass (*Cenchrus ciliaris*). Some of the legume species trialled include glycine (*Neonotonia wightii*), centro (*Centrosema pubescens*) and species of *Desmodium* and *Stylo*. Some of these grass and legume species would also be appropriate for planting in western Viti Levu. Notably, buffalo grass "is a strongly competitive grass which forms a dense weed free pasture under heavy stocking rates. It has proved to be very successful under Coconuts in Vanuatu" (Government of Vanuatu and AIDAB nd), and may be suitable for improved pastures in western Fiji.

From a policy perspective in Fiji, Manueli (nd) noted that "Production by grazing livestock remains limited by poor pastures resulting in poor productivity per head and per hectare. Improved pastures and the development of sustainable pasture management systems are necessary to ensure the survival of the sector. This will require an integrated approach to pasture management and will involve the investigation and correction of soil fertility problems, the introduction and screening of new grass and legume species, the establishment of farmer and staff training programmes, the establishment of on-farm demonstrations and equally importantly assistance to farmers in the marketing (especially in the case of beef farmers)." He further commented that "Currently, the Ministry of Agriculture Fisheries Forests and ALTA is limited in its ability to carry out the necessary pasture improvements due to a lack of skills on the part of livestock officers and their heavy involvement in regulatory and disease eradication activities. Hence assistance must be sought to carry out any comprehensive pasture improvement programme."

7. Priority tree species and potential agroforestry species mixtures for Fiji and Vanuatu

Steve Harrison and Robert Harrison

Abstract

A major challenge for the promotion of agroforestry expansion in specific locations in Fiji and Vanuatu is to identify species mixtures which are technically suitable and viable in terms of resource demands and financial performance. In ACIAR project ADP/2014/013, 'Promoting sustainable agriculture and agroforestry to replace unproductive land-use in Fiji and Vanuatu', an attempt has been made to identify mixed-species agroforestry (MSA) systems suitable for adoption on underutilised land in the Fiji Western Division on Viti Levu, and on unproductive coconut plantation land on Efate Island in Vanuatu. In this context, information has been obtained about site requirements of priority Pacific island tree species, and other tree and crop species suitable for use with these in agroforestry systems. This has involved a major literature review, as well as site visits, discussions with officials concerned with natural resource management, and landholder surveys. Based on information about priority species in the two countries, together with information on species–site matching, a suite of financial models for single tree and crop species has been developed for the focus areas of the ACIAR project. The financial models for individual species can be used in carrying out financial analysis of overall MSA systems, to assist in identifying promising systems and support measures which would be required to promote them, from a land-use policy perspective. Some validation of the individual-species models, and of the overall MSA system models, is needed before these can be promoted for specific areas.

INTRODUCTION

Agroforestry systems have much to contribute as a land-use practice in Fiji and Vanuatu, but the area planted to these systems has actually declined in recent decades, in large part due to an emphasis on larger scale plantation systems which originated in the colonial period, in particular for production of sugar, copra and beef. Deforestation, land degradation and urbanisation of the population have taken place in recent years. The potential benefits of restoring agroforestry have attracted substantial policy interest in recent years, to promote more sustainable land use, rural livelihoods, import replacement and improvements in human nutrition.

From a policy perspective, promotion of agroforestry requires that species mixtures be identified which include high priority tree and crop species, are edaphically suited to the land available for planting, have viable markets, and are efficient in terms of returns to capital, labour and land. A component of ACIAR project ADP/2014/013, 'Promoting sustainable agriculture and agroforestry to replace unproductive land-use in Fiji and Vanuatu', is to identify suitable mixed-species agroforestry (MSA) systems for western Viti Levu in Fiji and coastal coconut plantation land in Efate in Vanuatu. This working paper, and several others in this publication, as well as various spreadsheet financial models of individual tree and crop species, have examined land suitability and land-use issues, species–site considerations, as well as financial, social and environmental aspects, as a background to evaluation of promising MSA systems in the two countries.

This working paper summarises information on priority Pacific island tree species, progress on developing financial models for individual tree and plant species, and tentatively identifies promising tree and crop species combinations suitable for the focus areas of the ACIAR project.

PRIORITY TREE SPECIES IN FIJI AND VANUATU

Various lists of priority tree species for conservation and planting have been developed for the Pacific islands, including Fiji and Vanuatu, particularly in the last two decades. There would appear to be no single authoritative list in the individual countries, with preferred species being identified by governments, aid agencies and influential researchers. Some of the criteria which appear to have been taken into account in developing priority rating lists include the following.

- The need for conservation of genetic material, where due to logging and other actions the number of trees or particular genotypes has fallen to a low level.
- The proven performance of the species growing naturally, as a source of timber (e.g. lumber, poles, carving timber), food (e.g. fruit, nuts), or other products and services, including suitability for growing in particular types of sites.
- The international or domestic marketability of the timber and other products from the species.
- Species for which a high level of product value adding is possible.
- Species for which a high degree of genetic improvement is judged possible.
- Suitability of species for growing in MSA systems.
- The traditional values of the species to particular Pacific island communities.

Some of the lists of priority tree species that have been proposed in recent years are reported below.

Hald et al. (1999) and Sigaud et al. (1999) reported lists of priority tree species for Pacific islands compiled from workshop meetings and country reports of various countries. Each working group identified 10 high-priority native species:

- Melanesia and south-west Pacific: *Acacia* spp., *Agathis macrophylla*, *Calophyllum* spp., *Cordia subcordata*, *Diospyros* spp., *Endospermum medullosum*, *Intsia bijuga*, *Pometia pinnata*, *Pterocarpus indicus* and *Santalum* spp.
- Polynesia and the eastern Pacific: *Calophyllum inophyllum*, *Calophyllum neo-ebudicum*, *Cordia subcordata*, *Intsia bijuga*, *Planchonella samoensis*, *Pometia pinnata*, *Santalum* spp., *Syzygium inophylloides*, *Terminalia richii* and *Thespesia populnea*.
- Micronesia and north-central Pacific: *Artocarpus* spp., *Barringtonia asiatica*, *Calophyllum inophyllum*, *Cordia subcordata*, *Intsia bijuga*, *Morinda citrifolia*, *Pandanus tectorius*, *Pisonia grandis*, *Terminalia* spp. and *Thespesia populnea*.

A related document produced by the FAO Forest Management Division and coordinated by Pouru (2000) observed that

> Three indigenous tree species were identified as being among the top ten priorities in all parts of the Pacific:
>
> - *Calophyllum inophyllum* (beach mahogany, Alexandrian laurel),
> - *Cordia subcordata* (island walnut), and
> - *Intsia bijuga* (island teak).
>
> All three species are widely distributed, produce highly valued timbers, and are among the most highly valued woods for woodcarving and boat-building. In the case of *Intsia bijuga*, it is also found in inland lowland forests as well as along rivers and streams.
>
> In terms of regional priorities for action, the next most important species identified were:
>
> - *Santalum* species (sandalwoods), which are top priorities in south-west Pacific (3 species), eastern Pacific (2 species) and Hawaii (4 species);
> - *Calophyllum* spp. (especially *neo-ebudicum* and close relatives), all excellent timber species;
> - *Pometia pinnata* (Pacific lychee), an excellent timber and firewood species, and medicinal and food plant, commonly found in secondary forests, in shifting agricultural areas and around villages;
> - *Terminalia* species (including many fast-growing endemic inland species, and the coastal species, *T. catappa* or beach almond); and
> - *Thespesia populnea* (Thespians tree or milo), an important utility timber species and highly valued for woodcarving.
>
> These were followed closely by:
>
> - *Canarium* species (ngarli, nangai or galip nuts);
> - *Diospyros* species (Pacific ebonies);
> - *Morinda citrifolia* (Indian mulberry, nonu);
> - *Serianthes* species (mamufai, vaivai);
> - *Syzygium* species (asi toa, yasiyasi, fekika); and
> - mangroves (*Xylocarpus*, *Rhizophora* and *Bruguiera* spp.).
>
> The two highest priority introduced trees for the Pacific Islands were *Swietenia macrophylla* (big-leaf mahogany) and *Pinus caribaea* (Caribbean pine), both originating from tropical Central America.

A further comment by Pouru (2000) in relation to provenance is that "There are also several genera and species, some of which have important indigenous species in their native Pacific range, and which constitute priority species where they have been introduced elsewhere in the Pacific islands. These include *Acacia* spp. (especially *A. mangium*, *A. koa* and *A. spirorbis*), *Casuarina equisetifolia* (beach she oak or ironwood) and *Flueggea flexuosa* (namamau or poumuli)."

Channel and Thomson (nd, c. 2000) noted in relation to Vanuatu that "As a first step in conserving forest genetic resources, the Forest Conservation Unit of the Department of Forests has developed draft conservation strategies for four top priority Vanuatu tree species, sandalwood (*Santalum austrocaledonicum*), whitewood (*Endospermum medullosum*), Pacific kauri (*Agathis macrophylla*) and Santo kauri (*Agathis silbae*). Development of these strategies has involved input from the entire Department, and been assisted by the AusAID-funded SPRIG (South Pacific Regional Initiative on Forest Genetic Resources) ... An essential step in this process has been consultation with key stakeholders, including village communities, industry and NGOs. The conservation strategies are comprehensive and detail all relevant known information on the species, including biology, distribution, utilization, threats and recommended conservation measures."

In a regional workshop on forest genetic resources, FAO and SPC (2012, p. 34) reported a list of 26 priority species for the Melanesian countries:

Agathis macrophylla
Alphitonia zizyphoides
Canarium indicum
Dacrycarpus imbricatus
Dacrydium nidulum
Decussocarpus vitiensis
Degeneria vitiensis
Endospermum robbienum
Enspermum medullosum
Vitex coffasus
Eucalyptus deglupta
Eucalyptus pellita
Fagraea gracilipes
Flueggea flexousa
Gmelina vitiensis
Heritiera onithocephala
Myristica sp. *kaudamu*
Pinus caribbea
Podocarpus neriifolius
Pometia pinnata
Pterocarpus indicus
Santalum spp.
Sterculia vitiensis
Swietenia macrophylla
Tectona grandis
Terminalia catappa

Conservation International (2013, p. 41) chose a list of native species (plus two exotic species) for planting on a relatively dry site in a large forestry and agroforestry project in Ra province in northern Viti Levu, Fiji. The species chosen are as follows:

Retrophyllum vitiensis (Dakua salusalu)
Intsia bijuga (Vesi)
Bischofia javanica (Koka)
Gyrocarpus americanus (Wiriwiri)
Elattostachys falcata (Marasa)
Barringtonia edulis (Vutu Kana)
Palaquium porphyreum (Bauvudi)
Pometia pinnata (Dawa)
Inocarpus fagifer (Ivi)
Cinnamomum spp. (Macou)
Gymnostoma vitiensis (Velau)
Casuarina equisetifolia (Nokonoko)
Dacrydium nidulum (Yaka)
Gonystylus punctatus (Mavota)
Santalum yasi (Yasi)
Parinari insularum (Sa)
Eleocarpus spp. (Kabi)
Calophyllum inophyllum (Dilo)
Serianthes melanesica (Vaivai ni veikau)
Agathis macrophylla (Dakua makadre)
Myristica spp. (Kaudamu)
Calophyllum spp. (Damanu)
Endospermum macrophyllum (Kauvula)
Cananga odorata (Makosoi)
Dillenia biflora (Kuluva)
Podocarpus neriifolius (Kuasi)
Pagiantha thurstonii (Tadalo)
Tectona grandis (Teak)
Swietenia macrophylla (Honduran mahogany)

Padolina and Kete (2014) identified priority tree and crop species for agroforestry for Pacific island countries, presented as follows:

Timber and tree species

- Teak (*Tectona grandis*)
- Poloumi (*Flueggea flexuosa*)
- Caribbean pine (*Pinus caribaea*)
- Mahogany (*Swietenia macrophylla*)
- Tropical almond (*Terminalia catappa*)
- *Pandanus* spp.

Tree species for essential oil

- Sandalwood (*Santalum* spp.)
- Coconut (*Cocus nucifera*)
- Dilo (*Calophyllum inophyllum*)
- Mokosoi (*Cananga odorata*)
- Agarwood (*Aquilaria* spp.)

Trees that provide food, fruit and nuts

- Coconut (*Cocus nucifera*)
- Breadfruit (*Artocarpus altilis*)
- Coffee (*Coffea arabica*)
- Cocoa (*Theobroma cacao*)
- Ngale or canarium nut (*Canarium indicum*)
- Mango (*Mangifera indica*)
- Avocado (*Persia americana*)
- Papaya (*Carica papaya*)
- *Citrus* spp.

Multipurpose trees

- *Gliricidia sepium*
- *Azadirachta indica*
- *Morinda oleifera*
- *Morinda citrifolia*

Republic of Vanuatu (2014) noted that "Five tree species have been selected as priority species for reforestation. These are the Sandalwood (*Sandallum austrocaledonicum*), Mahogany (*Swietenia macrophylla*), Namamau (*Securinega flexuosa*)[1], Whitewood (*Endospermum medullosum*), and Nangai (*Canarium* spp.). The five species were selected according to the economic value and local use of each of the species, that is, Sandalwood is traded for its scented heartwood, Mahogany and Whitewood are high value commercial timber trees, Nangai is promoted for its nuts as well as timber and the Namamau for its local use for round poles for traditional houses."

A list of priority tree species for Fiji and Vanuatu was provided by K. Glencross (pers. comm. 2014), who carried out forestry planting trials in both countries. The key priority species for Vanuatu were identified as the native species *Endospermum medullosum* (whitewood), *Terminalia catappa* (Pacific or tropical almond, Bislama name natapoa), *Santalum* spp. including *S. alba* (sandalwood), *Flueggea flexuosa* (poulumi), *Canarium indicum* (canarium nut), *Intsia bijuga* (vesi), and the exotic species *Swietenia macrophylla* (mahogany). These same species were identified for Vanuatu, with the addition of *Inocarpus fagifer* (Tahitian chestnut) and *Artocarpus altilis* (breadfruit).

In a recent visit to Fiji a list of priority tree and plant species included in current silviculture research projects was provided by the Department of Forestry (Figure 1). This extended group reveals the wide interest in forestry and agroforestry research in Fiji.

In general, there is a reasonable degree of consistency between the choice of priority species for Fiji and Vanuatu. For agroforestry planting, the emphasis is on a collection of about 30 indigenous species which have proven performance growing naturally, but for which there is generally little experience of growth performance as a plantation species, though some have been grown in home gardens.

There are naturally differences in species choice depending on planting sites. In some Pacific islands there are notable rainshadow areas, e.g. on the western side of Viti Levu in Fiji. In the series of species profiles for Pacific island agroforestry edited by Craig Elevitch (Elevitch 2006), site requirement details provided include notes on the range of annual rainfall and the approximate number of drought months which the species can tolerate. Sandalwood, vesi and mango are identified as priority species which can tolerate relatively dry sites. A database of some priority species for Fiji and Vanuatu and their socio-economic and environmental characteristics is presented in Appendix A.

Some of the species often ranked as high priority are actually known to be not native to the Pacific islands, but have been grown there for many decades or even centuries, and so classify as traditional species. Two species which are relatively recent introductions to the Pacific islands that are often included in the priority lists are teak and mahogany. These are recognised as having reasonably rapid growth in plantations, timber with a favourable international recognition, and relatively wide site tolerance (particularly teak).

1 *Securinega flexuosa* is a synonym of *Flueggea flexuosa*, a species sometimes known as poulumi or flueggea.

1	Growth Studies on *C. inophyllum* (Dilo)	*Calophyllum inophyllum* (Dilo)
2	Mixed-species Woodlot Planting Trial for High-value Timber Production	*Dalbergia cochinchinensis* (Thailand Rosewood), *Dalbergia barrensis, Flindersia brayleana* (Queensland Maple), *Tectona grandis* (Teak), *Swietenia macrophylla* (Broad-leaved mahogany Prov. Costa Rica)
3	Forest Restoration Trial in Degraded Areas	*Santalum yasi* (Yasi Dina), *Santalum album* (Yasi-Ni-Idia), *S.yasi x S.album Hybrid, Tectona grandis* (Teak), *Swietenia macrophylla* (Broad-leaved mahogany Prov. Costa Rica), *Fluegea flexuosa* (Paumuli), *Agathis macrophylla* (Dakua-Ni-Solomoni), *Intsia bijuga* (vesi), Kaudamu, Moivi, Velau, *Acacia mangium, Acacia auricorliformis, Acacia crassicarpa,*
4	Growth Studies on Agar Wood	Agar-wood
5	Spacing Trial & Demonstration plot for Sandalwood	*Santalum yasi* (Yasi Dina), *Santalum album* (Yasi-Ni-Idia), *S.yasi x S.album Hybrid, Fluegea flexuosa* (Paumuli), *Coffea Arabica* (Coffee), *Cajanus caja* (Pigeon Pea), *Citrus reticulata* (Moli Madirini), *Citrus limon* (Moli Karokaro), *Fortunella* (Kumquat), *Mango Mangifera indica* (Mango), *Artocarpus altilis* (Breadfruit), Musa acuminate (Banana), *Musa sapientum* (Vudi)
6	Sandalwood Clonal Seed Orchard (CSO) & Gene Conservation Area (GCA)	*Santalum yasi*, *Citrus reticulata* (Moli Madirini), *Citrus limon* (Moli Karokaro), *Fortunella* (Kumquat), *Cajanus caja* (Pigeon Pea)
7	Commodity Profiling of 25 Priority Species	*Acacia richii* (Qumu), *Agathis macrophylla* (Dakua-Ni-Solomoni), *Alphitonia zizyphoides* (Doi), *Calophyllum inophyllum* (Dilo), *Calophyllum Vitiense* (Damanu), *Dacrycarpus imbricatus* (Aumunu), *Dacrydium nidulum* (Yaka), *Degeneria vitiensis* (Masiratu), *Endospermum macrophyllum* (Kauvula), *Eucalyptus deglupta, Fagraea gracilipes* (Buabua), *Gmelina vitiensis* (Rosawa), *Heritiera Onithocephala* (Rosarosa), *Intsia bijuga* (Vesi), *Kingiodendron platycarpum* (Moivi), *Myristica castaneifolia* (Kaudamu), *Palaquium hornei* (Sacau), *Pinus carribea* (), *Podocarpus neriifolius* (Kuasi), *Retrophyllum vitiensis* (Dakua Salusalu), *Samanea saman* (Vaivai-Ni-Veikau), *Santalum yasi* (Yasi Dina), *Sterculia vitiensis* (Waciwaci), *Swietenia macrophylla* (Broad-leaved mahogany), *Tectona grandis* (Teak)

Figure 1. Priority tree and plant species in current silviculture research projects in Fiji (list provided by the Fiji Department of Forestry).

Notably, eucalypts appear to have fallen out of favour in the species lists, although two are included in the species lists above, i.e. *E. deglupta* (the only eucalypt species occurring naturally in the northern hemisphere) and *E. pellita*. Eucalypts—mostly of Australian origin but with extensive hybridisation in Brazil in recent years—are grown in plantations throughout the world. These species have highly effective water management, and would be well suited to growing in western Viti Levu, although they are in general not well suited to agroforestry plantings.

PROGRESS ON DEVELOPING FINANCIAL MODELS FOR INDIVIDUAL TREE AND PLANT SPECIES

Substantial progress has been made in financial modelling of priority tree species for Fiji and Vanuatu in ACIAR project ADP/2014/013. The choice of species for inclusion in agroforestry financial models is based on recent subjective assessment of importance in the various lists reported above, the views of members of ACIAR research project teams, and discussions with natural resource management professionals in Fiji and Vanuatu.

Species for which financial models have been developed include the tree species:

- Avocado (*Persea americana*)
- Breadfruit (*Artocarpus altilis*)
- Canarium nut (*Canarium indicum*)
- Cocoa (*Theobroma cacao*)
- Poumuli (*Flueggea flexuosa*)
- Sandalwood (*Santalum austrocaledonicum*, *S. yasi*)
- Tahitian (Polynesian) chestnut (*Inocarpus fagifer*)
- Tropical almond, sea almond (*Terminalia catappa*)
- Whitewood (*Endospermum medullosum*)
- Vesi (*Intsia bijuga*)

as well as the root crop taro (dalo; *Colocasia esculenta*) and the green manure crop velvetbean (*Mucuna pruriens*). Separate financial models together with detailed reports explaining the rationale for parameter estimates have been prepared for each of these species.

ADAPTATION OF GROSS MARGIN BUDGETS FOR FINANCIAL MODULES

Because development of new financial models is highly time consuming, and recent gross margin (GM) budgets are available developed by Leslie (2013), the gross margins for several species—mainly annuals and short-rotation crops—have been adapted for use in MSA system models. The setting of the GM analyses is as income-earning opportunities for farming on land where sugarcane production has ceased, in western Viti Levu, Fiji. The format of the GM models is as one-page pdf files of Microsoft Excel spreadsheets. Modules consistent with the financial models developed for other species, which have been created by adaptation of the Leslie (2013) GM models, include three annuals, namely:

- Dryland taro (tannia, dalo-nitans; *Xanthosoma saggitifolium*)
- Sweetpotato (kumala; *Ipomoea batatas*)
- Cassava (*Manihot esculenta*)

and nine multi-year species:[2]

- Avocado (*Persea americana*)
- Kava (yaqona; *Piper methysticum*)
- Mango (*Mangifera indica*)
- Pacific kauri (*Agathis macrophylla*)
- Papaya (*Carica papaya*)
- Pigeonpea (*Cajanus cajan*)
- Pineapple (*Ananas comosus*)
- Plantain (*Musa* spp.)
- Sweet orange (*Citrifolia sinensis*).

The modules developed from the GM analyses are designed to complement the financial analyses of priority Pacific island tree species, in the development of models of MSA systems. All calculations for the GMs are on a 1 ha area basis.

The technique of GM analysis was developed mainly to evaluate the performance of annual crops in terms of revenue and direct or operating costs but excluding overhead costs. This annual budgeting approach is a quite different methodology to discounted cash flow analysis which is used in

2 Cassava can actually be grown as a multi-year species, and pigeonpea can be grown as an annual.

investment project evaluation. The GM budgets of Leslie (2013) are somewhat a hybrid of the two methodologies, in that they include the establishment costs (capital outlays) and annual operating costs for some multi-year species, including mango, sweet orange, banana and plantain, and kava.

Method of adapting the GM models to modules for financial analysis

A number of modifications were made to the Leslie (2013) GM budgets to derive the corresponding financial modules.

Adjustment of GM estimates for inflation. Because the Leslie models were prepared using data from late 2012, the cost and revenue parameters were updated for inflation, by multiplication by the factor 1.10. This corresponds to an annual inflation rate of 4%, which approximates the Fiji inflation rate reported on the web. Of course, costs and revenues associated with agroforestry projects will not necessarily change over time at the same rate as broad national consumer price indicators, and increases in wage rates (the major cost item for agroforestry projects) will differ from increases in prices of consumer products, but the approach adopted is considered reasonably reliable.

Using GMs as annual net cash flows for annual crops. In the case of the three annuals listed above, the GM budgets after inflation to 2015 prices are taken as satisfactory estimates of annual net cash flows, and their use assumes that no new capital outlays are required (e.g. land clearing to move a species to a new location within the agroforestry plot).

Within-year timing of cash flows. In the case of multi-year species, for which discounting of cash flows is required, the situation is more complex. GM analysis assumes that costs are spread uniformly throughout the year. By contrast, for discounting purposes in financial analysis cash flows are assumed to take place at discrete times—usually the beginning or end of a year—and some conventions are needed to arrive at the timing scheme. In this regard, capital outlays are assumed to take place at the beginning of the first year. A time period of year 0 was added to accommodate this, i.e. year 1 of the GM budgets is split into year 0 and year 1. Land preparation costs and expenditure on planting materials have been timed for year 0. On the other hand, in financial analysis operating costs and project revenues are typically assumed to take place at the end of each year. To accommodate this difference, the year numbers in the GM models (1, 2, 3, …) are regarded as end-of-year times for operating costs (for purchase of fertiliser, insecticides, pesticides and fungicides, and most labour costs) and project revenues.

Addition of capital outlays not included in the GM budgets. While the GM budgets generally include land preparation and purchase of planting materials, they do not include the cost of land clearing and lease registration and annual fees, purchase of knapsacks for spraying and buckets and crates for carrying fruit and nuts, purchase of farm tools and some other capital items. An attempt was made to estimate these costs. Also, in cases where these costs are common to two or more species, in the multi-species financial models they were placed in the front or summary spreadsheet, not in the sheets for individual species.

Project life. In that the GM budgets adopt relatively short project lives, the rotation length for some of the multi-year crops has been extended, a notable case being that of citrus from 8 to 20 years. In the case of pigeonpea, which can be grown as an annual or not replanted for up to about five years, a three-year rotation was assumed. For practical purposes, it is usually necessary to include only a sufficient number of years in financial models to determine whether the investment is financially viable. However, for timber species the project life or planning horizon adopted must extend to the harvest age, e.g. about 20 years in the case of sandalwood.

Annual labour costs and wage rates. The Leslie GM models include estimates of number of annual labour days required for each species, which were followed as much as possible. The GM models assume a wage rate of F$20/day. This was reduced for both countries, instead using the national minimum award wage (F$18.56 for Fiji and 1,400 vatu for Vanuatu). The rationale is that farmers are likely to do most of the labour tasks in agroforestry plantings themselves, and the opportunity cost of their time would approximate the minimum wage.

Other adjustments to parameter values. Where other information was available, particularly more recent information, some of the estimates of Leslie were replaced, particularly in the case of product prices. Apart from wage rates, the Fiji GM budgets formed the basis for the cost and revenue parameters for the Vanuatu agroforestry financial models.

The need for further data collection and model validation

Deriving annual cash flows on the basis of the GM budgets has required some compromises in financial evaluation, though the estimates appear reasonably sound. Should opportunity permit, it would be useful to collect further data and expert opinion to further enhance confidence in the financial estimates.

Priority or promising species for which financial models have not been developed

It would be useful to have financial models for other agroforestry tree and crop species, for example *Calophyllum inophyllum* (Alexandrian laurel, beach mahogany, oil nut tree) and the hardy biofuel species *Millettia pinnata* (pongamia). About 200,000 ha of the latter species have been planted to date by Biofuels International Fiji (Sapp 2014). However, development of spreadsheet models of further tree and crop species has not been possible within the time and other resources of the SRA.

TENTATIVE SUGGESTIONS FOR MIXED-SPECIES AGROFORESTRY SYSTEMS IN FIJI AND VANUATU

The collection of single-species financial models which have been developed in the ACIAR SRA provide a basis for developing mixed-species financial models. This would involve selecting individual species which are suited for similar sites—in terms of soil condition and slope, rainfall amount and distribution throughout the year, and temperatures—but also similar socio-economic and institutional factors. A notable example of socio-economic factors is that the growing of bulky products (e.g. logs, pineapples) may not be financially viable on outer islands of Fiji or Vanuatu, with low populations, because the transport cost for marketing in larger population centres may be prohibitive.

The following potentially suitable systems have been identified through consultation with various people, together with fieldwork and literature review.

Mixed-species agroforestry systems for Fiji

The range of tree and crop species which can be grown in the Western Division of Viti Levu in Fiji (including land previously cropped with sugarcane) is limited by the relatively low annual rainfall (about 1,800 mm per year) and annual dry period in winter. Mixtures could include the following.

- On favourable sites, breadfruit + pineapple + cassava, a mixture recently planted by Kokosiga Pacific near Nadi. On some sites, with relatively fertile and well-drained soil, avocados rather than breadfruit could probably be grown, with potentially higher revenue. Kokosiga Pacific are also growing citrus in this area. Bee-keeping is also a possibility.
- On medium-quality sites, vesi + sandalwood + one of cassava, xanthosoma (dryland taro), pineapple or kava, possibly also with bee-keeping. Vesi + sandalwood + a cash crop has been discussed by SPC.
- On poorer sites, mango + pineapple or cassava, possibly with beekeeping. (A mango + cassava system was observed near Nadi.)
- In relatively wet areas, tropical almond (*Terminalia catappa*) + taro, as suggested by Richard Markham, ACIAR.
- In relatively wet and even swamp or saline sites, Tahitian chestnut (*Inocarpus fagifer*) + taro (*Colocasia esculenta*), as observed on a wet coastal site near Nadi.

Mixed-species agroforestry systems for Vanuatu

- Cacao + sandalwood + vegetables, planted on sites cleared of natural vegetation or regrowth. In this system, being trialled by Mr Joseph Merit on Epi Island, vegetables are designed to provide an income in the first six months (tomatoes, lettuce and beans) and throughout the first three years (sweetpotato, yam, papaya and corn, with sweetpotato also a soil improver).

- On relatively dry upper slopes, sandalwood + short-term hosts (e.g. pineapple) + long-term hosts (e.g. citrus, casuarina).
- On relatively wet (downhill) sites and even in coconut plantations, Tahitian chestnut (*Inocarpus fagifer*) + taro (*Colocasia esculenta*), as observed near Nadi.
- On particularly wet lowland sites, tropical almond (*Terminalia catappa*) + taro, following a velvetbean green manure crop, as suggested by Richard Markham, ACIAR.
- Breadfruit (wide spaced) + papaya + citrus (perhaps lime).
- Whitewood + namamau (*Flueggea flexuosa*) + cassava + pineapple, as trialled in ACIAR project work in Vanuatu.
- Canarium (*Canarium indicum*) + citrus + mango + possibly short-term root crops.
- Some retained coconut palms + improved pastures + crops for winter feed supplementation, in relatively high rainfall areas.

Transitioning out of the current land-use system

It is expected that the current land use of sugarcane (Fiji) and coconut production (Vanuatu) would be retained in most locations where this remains financially viable (or viability can be increased) in terms of crop output, market availability and product price. Where sugarcane production has ceased, and on underutilised land on sugarcane farms, the question would arise as to what is the 'highest and best use' of the land. For prime land, this is likely to be some form of horticulture, which could involve growing vegetables or fruit trees. In fact, the Kokosiga Pacific plantings near Nadi approximate this. On more marginal land, where financial performance is likely to be adequate, the issues then become whether the landholder is interested in agroforestry, whether resources (notably capital and labour) are available, and whether market opportunities exist. Some form of funding or in-kind assistance as well as extension advice may be required.

As there is recent renewed interest in coconut production for products other than copra, a slower form of transition may be desirable. The majority of coconut plantations in Vanuatu are now aged, and are of the old tall rather than newer dwarf varieties, such that the trunks are suitable for milling. There is evidence of failure to collect fallen coconuts on outer islands including Epi, but on Efate there are stronger markets. In many parts of the world, including in the Philippines, there is strong demand for the coco-lumber which can be obtained from aged coconut palms, and research is being carried out into new uses of the timber. This requires development of processing infrastructure, such as equipment for plywood production, constructed near the source of supply to avoid high log transport costs. Another feature of coconut plantations is that they have wide spacing between palms, and provide partial shading for pasture or interplanting with other tree and crop species, such that the transition to another land use can be gradual. This suggests a strategy of retention of productive coconut plantations where reliable markets exist (e.g. where contracts with processors are available) and otherwise progressive intercropping and thinning of mature coconut palms where necessary to reduce the extent of shading. Again, some support measures may be required to assist landholders in moving to agroforestry systems.

CONCLUDING COMMENTS

Further developments in construction and testing of the multi-species financial models are needed, if these are to be used to generate or support policy recommendations. The models need to use national currencies (Fiji dollar or Vanuatu vatu) to be convenient for policymakers and landholders. Some standardisation of work rates is required, with separate rates for timber trees, fruit trees (which generally require particular attention at planting), and other crops. Some validation of physical and financial parameter values and other modelling assumptions used in the financial models of individual species is now required.

An additional challenge for MSA system models—not likely to be dealt with comprehensively in the current project—is to model the different parameter values required relative to the single-species models. Elevitch (2006) recommends major changes to tree spacing in mixed-species plantings relative to monocultures. As well, allowance is needed for differences in growth rates and yields due to interactions between species.

Finally, the financial models would benefit by taking into account research findings on agroforestry systems from current and recent research projects conducted in Fiji and Vanuatu.

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APPENDIX A. DATABASE OF SOCIO-ECONOMIC AND ENVIRONMENTAL CHARACTERISTICS OF SOME PRIORITY SPECIES

A small Microsoft Excel database has been prepared of selected Pacific island tree species with information about production, and social and environmental values. This database, presented as two screenshots below, was prepared early in project ADP/2014/013, and also the related project ADP/2014/012, as a basis for discussion within the research team over which tree species to focus on for the financial analysis. The species for which information was compiled include timber trees grown for sawlogs or special purposes including carving, canoe construction and oil extraction, and fruit and nut trees. Data have been collected from various sources, but especially 'Species profiles for Pacific island agroforestry', edited by C.R. Elevitch and published in 2006, and an earlier book by Elevitch and Wilkinson (2000). Online searches unearthed further useful information in ACIAR reports and from several databases, including the National Tropical Botanical Garden in Kauai in Hawaii; the Agroforestree Database in Kenya; Food Plants International Database for 'Helping the Hungry Feed Themselves', based in Tasmania, Australia; and the Feedipedia Animal Feed Resources Information System (of Institut national de la recherche agronomique (INRA), Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) and FAO). An amazing amount of information relating to agroforestry species is available in these sources. Some new information—for example on growth rates and harvest ages of species with little history of plantation or woodlot production—have been included in the database.

Some of the species have been identified as priority species for promotion and research in Fiji or Vanuatu (particularly sandalwood, vesi, whitewood, cocoa, canarium, tropical almond and Polynesian chestnut), and some have been the focus of ACIAR projects or included in ACIAR field trials. As well as timber production, some of these species are valued for nut and fruit production, and for non-market benefits including watershed protection and landscape rehabilitation. The detail provided is designed to assist in assessing 'novel' Pacific island tree species, most of which are not widely used in commercial forestry.

Information is included about growth rates, products, age of cropping or harvest, yield, environmental and social benefits, and particular features. The database is designed in part as a guide to which species to investigate in research into design of MSA systems. In relation to agroforestry systems, properties listed for the various species include growth rate and final height, main agroforestry use, products (e.g. timber, fruit, nuts, oil, medicinal products), site preference, age of cropping or harvest, fruit yield, and environmental and social values.

Economic, environnmental and social values of Pacific Island Tree Species

Species name	Breadfruit (*Artocarpus altilis)*	Tahitian (Polynesian) Chestnut (*Inocarpus fagifer*)	Tropical almond, sea almond (*Terminalia catappa*)	Poulumi, namamau (Flueggea flexuosa)	Whitewood (Endospermum medullosum)	Agathis macrophylla (Pacific kauri)
Height	12-15m	Up to 20m	25-40m	10-16m	20-40m	30-40m
Growth rate	0.5-1.5m/yr	Up to 2m/yr	2m/yr in early years	1.5m/yr early on, then slows	2.5-3m/yr	1-1.5m/yr
Site preference	Deep, fertile, well drained, wide site tolerance	High rainfall, low elevation, pH 5-14, wide site tolerance	Low elevation, mod. to high rainfall, coastal areas, wide range of light soils	Lowland, high rainfall, wide site tolerance (incl. poor drainage)	Lowland, high rainfall, wide range of alluv. and seas. inundated soils	High rainfall, friable well-drained soil, incl. elevated areas
Main agroforestry use	Soil stabilizn., overstory, home gardens	Soil stabilization, shade crop, overstory	Soil stabilization, coastal protection, intercropping for 2-3 years	Mixed spp woodlot, windbreak, home garden	Mixed species woodlots, silvopasture, short-term intercropping	Crop shade, silvopasture, intercropping with diverse tree/shrub understory
Products	Staple food, medicinal, lightweight wood	Edible nut, wood	Natapoa nut, timber, fuelwood, medicinal use (antibacterial)	Timber, fuelwood, traditional medicine	Timber	Timber
Age of cropping	Begins bearing in 3-5 yrs	Commence in yr 3-5, fully at 25 yrs+	3 yrs	Log within 10 years	Log at 30 years plus	Logging age uncertain
Yield	160-500 kg/yr	Up to 75kg/tree/yr	Up to 5kg kernel/tree/yr, high MAI	Low MAI	High MAI	Grows very big very slowly (MAI, 2-3m^3/ha/yr)
Environmental protection benefits	A large and long-term tree for vegetative land cover	Beach protection	Beach protection	A useful windbreak spp.	Revegn of disturbed sites, shade intolerant, wind resistant	
Social benefits		Timber can be carved; useful shade tree	An attractive ornamental with bright red-orange flowers	Relatively rapid income from posts		
Notable features	A traditional and nutritious Pacific Island food source	Slow to yield nuts. Long history of using wild trees; not often planted	One of the most common trees on tropical coasts; wind and salinity tolerant	Revegn of disturbed sites, durable short-rotn poles	Being promoted for production for the Japanese market, where light coloured timber is desired	Withstands strong winds

H	I	J	K	L
Economic, environnmental and social values of Pacific Island Tree Species (contd)				
Canarium nut (Canarium indicum)	Kamani, dilo, Alexandrian Laurel, beach mahogany, oil nut tree (*Calophyllum inophyllum*)	Sandalwood (*Santalum austrocaledonicum, S. yasi, hybrids*)	Vesi (*Intsia bijuga*)	Cocao (*Theobroma cacao*)
30-40m	8 - 20m	5-12m	7-25m	4-10 m, but can grow much taller when shaded
0.6.2m in 1st year, 2.5-3m for next 5-6 yrs	Less than 1m/yr	0.3-0.7m	1.5m/yr	Fairly rapid. Tree height may be managed to less than 4 m
Med to heavy, moderate to high fertility, free or impeded drainage	Low elevation riverine sites, 1-5 m rainfall, sandy well-drained soils, incl. beaches. Tolerates shallow and saline soils.	Can tolerate poor soils, low rainfall	Coastal, well-drained to swampy, alkaline, 1.5-2.3 m annual rainfall	Well drained, for deep taproot (2m) and extensive surface roots. Prererably high organic matter. Bean drying is difficult in wet areas. Tolerates dry conditions
Home garden, windbreak, mixed woodlot	Mixed woodlot, windbreak, home garden. Poor form, broad crown and heavy shade	Homegardens, MSA	Coastal protection and soil stabilization, windbreak, ornamental	Can be grown in partial shade, with coconuts, sandalwood and various other species
Nuts, timber, traditional medicine	Timber, highly valuable seed oil (for medicine, cosmetics, varnishes and lamps)	Caring timber, oil, perfumes, incense, religious ceremonies	Timber, medicinal, fuelwood, craftwood	Pods, dried beans, cocoa powder, cocoa butter, chocolate
Begins year 7, high at 10-15 yrs	No information found	Edible seed	No crop cropping	4 yrs, increases to peak in year 8
750 kg/ha, then 1.8-3.1t kernel-in-testa (KIT); high timber yield	Timber yield not known; 100 kg nuts/tree/year	Small, low-diameter trees	Probably no harvest in less than 30-40 years	2-2.5 kg dried beans/tree/year
Ornamental and shade, bird and bat habitat	Coastal stabilizaation, shelter belts, windbreaks	Salinity remediation, bird habitat	Coastal protection and soil stabilization, windbreak	Organic branding possible, but risk of clearing native forests and exploiting child labour.
Wood for boats and canoes, resin burning in ceremonies, torches	Attractive ornamental shade and shelter tree. Wood suitable for carving, cabinet making and boat building	Religious ceremonies; bird habitat	Cultural importance	Major opportunity for value adding, forming grower cooperatives. Can suspend harvesting for decades if price falls, then reactivate trees. Jobs for women and youths.
Important tree in customary life in Melanesia, incl. Vanuatu	A hardy ornamental. Sacred in some Pacific Islands, planted alongside temples. Shallow spreading root system and withstands typhoons. Nuts not edible	Very valuable heartwood in roots from about year 20; from stems by year 25	Priority species in Fiji. Very highly valued tree, for wood carving, furniture, house building	Very high value crop. Risk of price variability, pests & diseases, child exploitation

8. Financial models of multi-species agroforestry systems in Fiji and Vanuatu

Steve Harrison and Robert Harrison

Abstract

This paper brings together many of the considerations on multi-species agroforestry (MSA) examined in the above working papers. The complexities in designing MSA mixtures for particular settings are examined. Some parallels and differences are drawn between designs of mixed-species plantation systems that were adopted for rainforest cabinet timbers in tropical north Queensland and MSA systems for ACIAR project focus locations in Fiji and Vanuatu. It is demonstrated that for various reasons the design and financial analysis of MSA systems are much more complex than for mixed-species timber plantations; various bio-physical and socioeconomic factors must be taken into consideration in designing coherent mixtures. In developing MSA system financial models for Fiji and Vanuatu, considerable effort was required to carry out species–site matching for priority tree species, determine technical aspects (such as site amelioration, species compatability, shading requirements and equipment needed), examine labour requirements and cash flows over time, and sketch field layout diagrams for species mixtures including the pattern of intercropping and how this would change over time. Finally, five MSA models which have a relatively high likelihood of being successful in Fiji and Vanuatu according to biological and financial criteria were identified and their rationales described. Detailed financial performance estimates for these models are provided in Working Paper 9 (Screenshots of multi-species financial models and explanatory notes). Also, financial performance has been estimated for eight priority tree and crop species not included in the MSA models, but available as modules for further agroforestry system designs. A table of financial performance for these eight species and interpretation of the findings is provided in Appendix A of this working paper. Calculations have been made in Fiji dollars per hectare of planted area. These species and estimated net present values, and land expectation values as a better criterion for comparison of species, are as follows: whitewood $5,418 ($6,898), vesi –$2,054 (–$2,153), flueggia $1,505 ($3,614), Polynesian chestnut $11,734 ($13,028), tropical almond $5,084 ($5,645), avocado $48,175 ($70,353), banana $43,337 ($163,556) and taro $20,160 ($97,785). The latter two species have particularly high labour requirements.

SOME EXPERIENCES IN DEVELOPING MIXED-SPECIES FORESTRY MODELS FOR NOVEL TREE SPECIES IN TROPICAL NORTH QUEENSLAND

It would be highly convenient if a collection of financial modules of individual tree and crop species could be developed, such that modules for several species could be coupled together to develop multi-species agroforestry (MSA) system designs to suit grower interests. Thus if a grower said they were interested in growing say canarium, tropical almond, cocoa and plantain, financial models could be coupled together for these species, and for a mixture of them planted together, at the same time. Some experience in financial modelling of tropical rainforest cabinetwood species in tropical north Queensland provides insights into the suitability of this approach.

Herbohn et al. (1998) reported the development of a Microsoft Excel forestry model (the Australian Cabinet Timber Financial Model, ACTFM) to predict potential returns from small-scale plantations of high-value Queensland tropical rainforest cabinet timbers for which there was little experience of commercial plantation production. A somewhat more advanced Visual Basic financial model (with this platform needed to overcome capacity limits of Excel) was reported by Herbohn et al. (2009). This is a whole-farm financial model—referred to as the Australian Farm Forestry Financial Model (AFFFM)—which can be used to evaluate the financial performance of mixed tree, crop and livestock production.

The ACTFM and AFFFM were designed for examining financial performance of mixtures of up to six Australian rainforest tree species. Most of the species for which data were collected had not been used in commercial forestry, an exception being hoop pine (*Araucaria cunninghamii*). Rather, they were 'novel' tree species, and considerable effort was expended by a group in the Cooperative Research Centre for Tropical Rainforest Ecology and Management (CRC-TREM, later known as the Rainforest CRC) to obtain critical biological and financial parameters. It was assumed that the trees would be grown in plantations on farms as mixed-species forestry, with each species in a mixture planted at the same time, though in individual rows. The models were primarily designed for similar types of species grown in relatively similar land and weather conditions, i.e. rainforest cabinetwood species in the Queensland wet tropics. Confidence was built up in the financial models by their repeated use over several years, with progressive refinement to the parameters. The model was tested with forestry reseachers and extension officers, and a university class. During this time a menu system, the facility to overwrite default parameters, error-checking of input data and report-writing facilities were added. An important finding of this research was that any thought that the models could be used by farmers as decision-support systems (DSS) was soon dispelled. However, forestry extension officers did appear to find the models useful.

The research into financial modelling of MSA systems in ACIAR project ADP/2014/013, 'Promoting sustainable agriculture and agroforestry to replace unproductive land-use in Fiji and Vanuatu', soon revealed a number of complexities posing challenges for the biological and socioeconomic credibility of a DSS for MSA. Some of the limitations or obstacles are outlined below.

COMPLEXITIES IN MIXED-SPECIES AGROFORESTRY FINANCIAL MODELLING

'Novel' tree species and scarcity of information for financial modelling

The tree species for which financial modelling has been conducted in ACIAR project ADP/2014/013 are by deliberate selection Pacific island species which have been harvested from the wild but for which there has been little or no planting in single- or mixed-species woodlots or plantations until very recently. In about the last five years, some species mixtures have been planted in Ra Province in the 'intermediate' zone of northern Viti Levu, but the optimal harvest age of trees in these plantings is still unclear. On the other hand, more experience is available for a few fruit tree species (including mango (*Magnifera indica*) and citrus) and vegetable species (including breadfruit (*Artocarpus altilis*) and avocado (*Persea americana*)), together with a wide range of horticultural crops, which can be grown together with novel tree species. However, there is very little information available about the plantation performance of many of the priority timber and nut species. Added to this limitation is the small amount of validation which has taken place with regard to models of financial performance of individual species. For some tree species, it is simply not possible to make accurate predictions of harvest age. Can vesi, Pacific kauri and other novel species be harvested in 30–40 years, or is it necessary to wait for 80 years or more? Does sandalwood require 15 years or 30 years to develop high quality heartwood? These are still open questions, and a stronger research basis (say backed by a Delphi survey) would be desirable before any advice is given to growers.

The critical requirement of species–site matching

Yields of agroforestry species, and even their successful establishment and later survival, depend on the suitability of the planting site in terms of weather (including temperatures, rainfall and length of dry season), soil physical and chemical conditions, and other factors. For example, the choice of species to grow on relatively steep and degraded sites with annual rainfall averaging less than 1,800 mm and very little winter rain in Fiji will be much more limited, and the yield less, than on relatively flat land with annual rainfall averaging 3,000 mm and well distributed between months, in Vanuatu. In fact, in the more difficult sites the seedlings might not even survive.

Species mixtures versus discrete species blocks

Mixtures of tree and crop species can be grown in discrete blocks for each species, in rows for each species (perhaps alternating or intercropped), or as 'intimate' mixtures (with species placement often relatively random). For example, suppose an agroforestry system of breadfruit and pineapple is to be grown. The field layout could include separate blocks of each species, or the pineapples could be planted between—and even within—rows of breadfruit trees. In this latter case, the breadfruit trees and pineapples could be initially planted at their normal spacing, in an intercropping arrangement. If the two species were planted in separate blocks then the total area planted would be the sum of their individual areas. It the two species were intercropped, the total area planted would be much more than their individual areas. After a time the area of the intercrop would have to be reduced, and perhaps entirely eliminated.

The arrangement of single rows of individual species is widely practised. Stand management—including pest control and harvesting—is facilitated in this arrangement. For example, consider the harvesting of timber trees where separate species comprise individual rows. If all stems of a particular species are felled at the same time, this can be achieved by felling along rows, with little collateral damage. Another advantage of grouping planting by species is that the more wind- and cyclone-tolerant species can be located upwind, so as to maximise the protection of other species. Harvesting of the short-rotation species increases the row spacing for the longer term taller tree component. Intercropping results in a saving in weed control and pruning effort and cost, and fertiliser can be shared between species.

Variation in tree spacing and stand density when planting species mixtures

Some major differences between tree and plant spacing may be required in monoculture, mixed-species forestry and mixed-species agroforestry. For example, Thomson (2006, p. 10) recommended an optimal spacing for whitewood (*Endospermum medullosum*) when planted alone of 10–12 m between rows and 2–3 m within rows, but with the inter-row spacing halved if whitewood was grown together with *Flueggea flexuosa* (poulumi, namamau), which could be harvested after about seven years. This incidentally will reduce the thinning cost and to some extent the weed control cost of whitewood. Another example of variation in tree spacing recommended by Hebbar et al. (2011) is halving of the planting density of cocoa (*Theobroma cacao*), e.g. from 1,000 stems per hectare (sph) as a monoculture to 500 sph when grown in a polyculture. Such a system generates a more regular income stream over time than growing cocoa alone.

Further potential benefits from species interactions

The reduced thinning and weed control effort in the whitewood and cocoa mixtures described above are examples of beneficial interactions arising from intercropping. Much has been written about the general advantages of species interactions, and this has been a rationale for their promotion, particularly in developing countries. Mixtures can provide microclimate benefits, more efficient use of above-ground resources (particularly sunlight) and below-ground resources (accessing different stocks of soil nutrients and soil water at different depths), reduced pest and disease damage from greater separation of pest and disease hosts, sharing of organic matter from leaf fall, thinnings and prunings, and various other benefits. Some allowance for these benefits can be incorporated in financial models of agroforestry systems.

Short-term species in MSA systems

Where trees and food crops are grown, intercropping is often practised to generate food or income in the initial few years. This is particularly the case with vegetables and root crops (including taro for which corms rather than roots are actually harvested). As canopy closure in the taller species is approached, annuals and other short-rotation species are shaded out. It may be possible to grow the more shade-tolerant species, such as taro and pineapple, for three to six years, depending on the growth rate of the taller species. *Flueggea flexuosa* is frequently mentioned as a short-rotation timber species, for production of fence posts in about seven years and short poles in about 12 years.

Some crop species which are particularly demanding on soil nutrients, notably root crops, are often grown for only a few years at a particular site, then may have to be moved to a new area (perhaps recently under fallow). Under this system, a series of short-term crop sequences is grown, which requires more complex financial modelling.

Multiple varieties and staged planting and harvesting of food crop species

Particularly for food crops with a relatively short shelf life (including root crops), planting times and varieties of individual species may be varied to ensure a longer period of harvest and a continued supply of produce for domestic consumption or sale, as well as to spread labour demands over time and reduce market risk. There may also be some limited scope for delaying the harvesting date (in a sense, storing the crop in the field for a few weeks), as is sometimes practised with taro. This could be dealt with in financial modelling by treating alternative varieties and harvest timing as alternative crop activities.[1]

Wildfire, land degradation and the need for land rehabilitation before planting

In relatively harsh planting sites such as western Viti Levu, there are frequent fires in the dry winter season attributed to various causes, which destroy organic matter, cause surface soil compaction, and damage crops, particularly on sloping land and areas covered by inferior grasses (e.g. mission grass). This has the effect of both causing soil loss and damaging the vegetation. Land degradation raises particular problems for MSA establishment, and in some cases land rehabilitation actions are needed for two or three years, through a weed fallow to achieve 'site capture through canopy closure'. The growing of a green manure crop or deep ripping are alternatives for improving soil permeability. From a financial modelling perspective, the year of planting might then not be year 0 (immediately), but rather end-of-year 2 or 3, with revenue generation delayed. Land rehabilitation increases the capital outlay and reduces the net present value (NPV) of agroforestry plantings. Fires also impose a serious risk to yield, and a major psychological barrier against establishment of agroforestry, unless costly crop protection measures are conducted. Some recognition of these costs and risks is needed in financial modelling.

Making allowance for planting site quality

Even when tree and crop species are judged to be suitable for growing at a particular site, their performance (e.g. growth rate, yield and product quality) will depend on the site quality. A widely used concept when modelling commercial forestry production is the site index. This is defined in Foresters Consulting (nd) as: "Site index (SI) is a measurement commonly used by foresters to describe the productivity of a site. Typically this measurement is used to describe sites growing well-stocked even-aged forests. Site index is the average height of the dominant and codominant trees on the site, at a given age (base age)." For novel tree species, this type of information generally is not available. A more simple expedient for financial modelling of MSA systems is to apply a percentage rating for yield (and perhaps also for management) of a particular site in relation to average performance, for one or more species in the mixture. Thus for example an index of 80% for a somewhat degraded site would imply a 20% yield reduction relative to a typical site. The growth and yield data contained in the Pacific islands species profiles compiled by Elevitch (Elevitch 2006) presumably apply to average or above-average sites. Obviously engaging the judgement of experts in the sense of people familiar with performance of the species on a range of sites would increase the credibility of estimates.

Agroforestry 'project' life

It is not practical to set a fixed number of years for which financial performance of agroforestry systems

1 In the language of mathematical programming, a technique for determining the most profitable set of farm enterprises given various constraints on land, labour, capital and other resource inputs, an *enterprise* is production of a particular tree, crop or livestock species, and an *activity* is a particular form of organisation of an enterprise. Thus crops of say taro planted at different times throughout the farming year would be classed as different activities of the taro growing enterprise. Some examples of activities in linear programming models (and mathematical programming models more generally) in farm planning can be found in Dent et al. (1986) and Dayanandra et al. (2002).

is evaluated. Often using a relatively short planning period—say 10 to 20 years—will be sufficient to determine whether the system is financially viable. However, when one or more timber species is included it is necessary to include sufficient years to cover the harvest age of these species.

The need for growing shade species

Some species are likely to perform poorly after outplanting if shading is not provided initially. For example, canarium, cocoa and taro (an annual vegetable crop) are considered to require a reduction in sun intensity of the order of 50% when outplanted. The shade could be provided by use of artificial shade structures or having shade species present when outplanting. Under the latter strategy, planting of these sensitive species would likely be delayed for at least a year until sufficient shade becomes available. This of course needs to be recognised in the agroforestry system design and financial analysis.

Species choice in relation to ability to spread farm labour demand peaks

Some seasonal labouring jobs in Fiji and Vanuatu provide wage opportunities for landholders, e.g. sugarcane harvesting in Fiji. Agroforestry species may be chosen for which labour demand does not crowd out this period (in general spring), so as not to lose income or reputation as a reliable seasonal employee. Time of planting as well as number of labour hours required can be an important consideration for some farmers in viewing agroforestry systems.

Common capital requirements across species

Any costs of obtaining permission to use land (e.g. lease fees and annual payments to traditional owners) and to prepare land (e.g. land clearing costs) may be common costs across all species grown in agroforestry mixtures. Similarly, some overhead cost items (a form of capital outlays), such as purchase of hand tools (axes, grubbers, files, hoes, knapsack sprayers, buckets and crates for carrying produce), and buildings or equipment needed for post-harvest processing, will often be used by more than one species in an agroforestry system. The purchase of draught (work) animals would be another example. In that the investment project is the overall MSA system, it does not really matter where common costs are included in the analyses, but perhaps the simplest approach is to include these in the front or summary spreadsheet.

Overhead costs and scale of planting

While it is usual (and convenient) to develop financial models for timber and agroforestry systems on a 1 ha area unit, the scale of planting in agroforesty systems can vary widely. Home gardens and farm plantings are usually less than 1 ha in area, while more 'commercial' plantings may cover several hectares. Overhead costs (such as those in the common capital outlays mentioned above) typically do not vary greatly with area planted. The smaller the area planted, the greater the overhead cost (a component of capital outlays in discounted cash flow (DCF) analysis) per unit of output. By including overhead costs in the control spreadsheet, any economies of size are automatically accommodated in the financial analysis.

Post-harvest processing costs and returns

For a particular tree and crop combination, the degree of post-harvest processing can vary greatly, and the extent assumed needs to be clearly specified in the description of the system. In general, rural policy is to promote value adding, including post-harvest processing, to increase returns to growers rather than middlemen. Research and facilitation is being carried out in Vanuatu on drying and further processing of cocoa beans. If this can be done on a community basis, growers could receive increased bean prices, which might make a major difference in terms of financial viability for growing cocoa. For timber species which are valuable for carving timber or oil extraction (e.g. vesi, sandalwood), post-harvest processing could improve the financial attractiveness of including the species in agroforestry systems.

Costs which are particularly difficult to estimate

Some costs will vary with the particular location and farming circumstances. Notable examples are cost of access to land, land clearing, and purchase of tools and equipment. It is difficult to estimate what charges will be imposed on those who wish to establish agroforestry on customary or leased land,

and these charges do seem to be to some extent a matter of negotiation. On land which is already leased from customary owners, it could be assumed that no additional annual charges are required to adopt agroforestry. However, the leases set out precisely the purposes for which the land can be used, and it is probably unlikely that this would include forestry or agroforestry. Even farmers on customary land are sometimes advised to take out leases to secure harvest rights, leases apparently being a relatively secure and long-term form of tenure, although it is not clear how fees are likely to change over time. Some ballpark figures obtained for use of customary land for agroforestry on a Fiji field visit include a lease application processing fee of about F$1,000/ha and an annual lease fee of between F$1 and F$200/ha. It seems that these costs vary with land location and quality, leading to a suggestion that agroforestry may be more profitable away from the most populous islands.

The amount of expenditure required for tools and equipment will depend on the current land uses before agroforestry is introduced. If the farmer is currently engaged in horticulture, then they could already have most of the equipment needed. Land clearing costs will depend on the current land use. If the land is already used for some form of cropping, then the cost will be small. If forest or regrowth has to be cleared, a major cost may be involved. Land leasing and clearing costs and costs of plant and equipment would usually be included as common costs across species in financial models of agroforestry systems.

Recommended farming practice versus actual practices of farmers

The practices adopted by the majority of farmers often differ from those recommended by extension officers. Notable amongst these are the use of fertilisers and crop protection chemicals (weedicides, insecticides, fungicides). For the main part, recommended practices such as those of Leslie (2013), which include adequate allowance for fertiliser and crop protection, have been included in the financial models. In many cases farmers will have considerably lower costs, due to use of traditional crop protection measures and organic fertiliser, although there will sometimes be a major financial impact in terms of yield foregone.

Currency units for financial analysis

The financial analyses for individual species in ACIAR project ADP/2014/013 are in general developed for particular species in a particular country. The currency units for cost and revenue parameters used for the MSA systems are those for the country for which the mixtures are most applicable, i.e. either Fiji or Vanuatu.

The cost of labour

Labour—typically the largest single input in agroforestry financial models—is conventionally costed at an imputed daily wage rate for the farmer and perhaps other members of the farm family. This can be approximated by the national minimum wage. If a farmer could earn considerably more from off-farm work, it would not be economically rational for them to engage in agroforestry. Fortunately, both Fiji and Vanuatu have recently announced minimum legal wage rates.

Fiji introduced a new minimum wage of F$2.32/h in February 2015, to take effect from 1 July 2015 (Fiji Government 2015). Assuming an 8-hour day, this is equivalent to F$18.56/day. As of May 2014, the minimum wage in Vanuatu was set at 170 vatu/h (VCCI 2014). The annual inflation rate in Vanuatu in recent years has been about 3%, and "In 2015, Vanuatu's Average Inflation is expected to be 3.00 percent change" (Trading Economics 2015). Adjusting for inflation for one year, and assuming an 8-hour working day, the Vanuatu daily wage is about 1,400 vatu.

At the exchange rate with the Australian dollar at the time of writing (May 2015) of F$1 = A$0.62, the Fiji minimum wage is equivalent to about A$11.50/day. The exchange rate for 1 Vanuatu vatu was A$0.012 at that same time, so a daily wage of 1,400 vatu is equivalent to about A$16.80/day.

Consistency of work rates

Given the importance of labour costs in financial modelling, an effort was made to obtain reliable and consistent work times for various activities and to

Table 1. Work rates for main silvicultural activities.

Task	Rate (min/plant)			
	Timber trees	Fruit and nut trees	Shrubs	Root crops
Land preparation	0	2	2	1
Hole digging and planting	10	15	5	0.5
Fertilising or mulching at planting	2	2	2	5
Subsequent fertilising	0	4	3	5
Ring weeding, per round	5	7	5	0.25
Pruning, low	3	6	2	0
Pruning, high (e.g. pole pruning)	6	10	2	0
Thinning to waste, small trees	2			
Thinning to waste, large trees	8			

achieve some consistency across species. An important source of estimates was N.E. Gregorio (pers. comm. 2015), who has been organising agroforestry plantings in Leyte, the Philippines. Table 1 gives the work rates for silvicultural activities. Some variation was included within these rates, depending on tree size and other factors.

Other work rates

- Site clearing: highly variable depending on site—say 12 h/ha
- Site fencing, when required—say 16 h/ha
- Travel to field site and set-up time (including tool sharpening)—10 min
- Field layout: 8 h/ha (plus time when hole-digging)
- Transport of seedlings to field site: 1 min/seedling
- Nut collecting from ground: will vary with species—say 4 min/kg (based on author's experience with macadamia nuts)
- Nut husking: will vary with species—say 6 min/kg (based on author's experience with macadamia nuts)

Continuous validation efforts on the financial models, and updating of parameter estimates

It is to be noted that new parameter information is being progressively obtained relating to agroforestry systems in Fiji and Vanuatu. This poses a problem for version control of financial models, and for teamwork in development, testing and refinement of financial models in the ACIAR small research activities (SRAs).

THE MSA SYSTEMS SELECTED FOR FINANCIAL ANALYSIS AND REASONS FOR THEIR CHOICE

Various potentially viable agroforestry systems have been identified in ACIAR project ADP/2014/013. Given the time constraints, five of these species mixtures have been chosen for detailed analysis, as potentially suitable in Fiji, Vanuatu or both. These are agroforestry model (AFM) 1 to 5:

- AFM1: mango (*Mangifera indica*) + cassava (*Manihot esculenta*)
- AFM2: breadfruit (*Artocarpus altilis*) + pineapple (*Ananas comosus*) + cassava (*Manihot esculenta*)
- AFM3: citrus (*Citrifolia sinensis*) + sandalwood (*Santalum yasi*) + pigeonpea (*Cajanus cajan*)
- AFM4: cocoa (*Theobroma cacao*) + sandalwood (*Santalum austrocaledonicum* or hybrid) + sweetpotato (*Ipomoea batatas*)
- AFM5: canarium (*Canarium indicum*) + plantain (*Musa* spp.) + kava (*Piper methysticum*) + Pacific kauri (*Agathis macrophylla*).

Each of the species mixtures has been observed or suggested for either Fiji or Vanuatu, although some simplification has been made in the models in terms of number of species included. The analysis is to some extent an exploratory one, and is designed to illustrate how agroforestry systems can be evaluated in financial terms. Further validation is required before these models could be used for policy support.

AFM1: mango + cassava

This system is loosely based on a mango and cassava system observed in western Viti Levu, Fiji. The combination of these species is well suited for a relatively dry and difficult planting site. Mango is a popular and versatile fruit, and cassava is as a particularly widely grown root crop. Mango is relatively drought resistant, and even needs a dry period to trigger fruit production. An alternative species for cassava would be *Xanthosoma saggitifolium* (upland taro or tannia) which, unlike Colocasia taro, is tolerant of relatively dry sites. Notably, because of intercropping the total area cropped (at normal planting rates) in the first year is more than 50% larger than if the species had been grown separately. Further, maintenance of the cassava means that weed control required for the mango component is limited to only part of the overall area.

AFM2: breadfruit + pineapple + cassava

This mixture is an approximation to that planted by Kokosiga Pacific near Nadi in western Fiji. The model provides a simple illustration of how a tree food species,[2] a fruit and a root crop can be grown on a relatively flat and fertile area in western Viti Levu. Citrus is grown nearby, and could also be included in the mixture. In locations towards the 'intermediate zone' of Ra province with a more favourable rainfall pattern the mixture could probably be grown successfully on sloping land. It is assumed that breadfruit is intercropped with pineapple, but cassava is grown as a separate block. Intercropping of breadfruit trees with pineapple is assumed to continue for 10 years.

AFM3: citrus + sandalwood + pigeonpea

This mixture was observed in the 'intermediate zone' in northern Viti Levu, where there was strong interest in growing a small number of sandalwood trees, but a recognised need for an income flow over the 20 years or so before the sandalwood would be ready for harvest. Citrus and sandalwood could be grown in the same row, with two citrus trees to each sandalwood tree, i.e. the sequence CCSCCSCC…, with spacing of 3–4 m. The citrus would be a long-term host for the sandalwood. Pigeonpea is a drought-tolerant nitrogen-fixing species, and is an important food crop in many developing countries. Pigeonpea is described by CTAHR (2002) as "an erect shrub or short-lived (1–5 years) perennial legume often grown as an annual crop, 1 to 4 meters high". It is assumed that this species will be planted between the tree rows, at relatively close spacing, and could contribute as a short-term host for sandalwood. The agroforestry system would have a substantial initial establishment cost and labour demand, and is probably not upscalable.

AFM4: cocoa + sandalwood + sweetpotato

This was a system observed in Vanuatu, although a wide range of vegetable crops was included. It is a system requiring rather skilled management, but was designed and implemented by a farmer. While shading is often recommended for cocoa establishment, no shading was used in the planting observed. Land carrying regrowth species was cleared and cocoa and sandalwood were planted at the same time. In the financial model, the field layout includes these two species both planted on a 7 m × 5 m spacing. Both species are assumed to be planted in staggered 5 m × 3.5 m rows, such that each sandalwood tree is surrounded by four cacao trees. Both tree species are relatively small and slow growers, so moderately close spacing is possible.[3] Cocoa trees start to crop at an age of 3 to 5 years, and earlier with the new varieties. Yield increases gradually until an age of about 10 years. Cocoa has an expansive root system, and can act as a long-term host for sandalwood. The optimal age for sandalwood harvesting appears to be about 20 years. Sweetpotato is included in the mixture as a cash crop and to contribute to weed control, with vines planted within and between cocoa and sandalwood rows. Sweetpotato could be replaced by or mixed with

2 There is some debate in the literature about whether breadfruit is a fruit or a vegetable, and comment that it is eaten most often when immature as the latter, but has a sweet taste when ripe justifying the name of a fruit.

3 As noted by Hebbar et al. (2011, p. 9), "Currently there are no standard spacing recommendations for cocoa", and "Optimal spacing for cacao trees varies depending on the management system and ranges from 2.5 x 2.5 m … and 5 m x 5 m. … In Asia, cacao tree density averages 1000 trees/ha."

other short-term fruits and vegetables. After a few years the trees would reach canopy closure, so growing of fruits and vegetables would cease.

AFM5: canarium + plantain + kava + Pacific kauri

Canarium is a large nut-bearing tree which can attain a height of 40 m and a crown diameter of 30 m, and has been widely planted in Pacific island countries, and promoted for intercropping.[4] Wide-spaced planting is recommended.[5] In this system, it is envisaged that the canarium and kauri are planted on a 9 m × 9 m grid, and that the two crops are grown between them. Kauri and plantain are planted immediately, with the latter first planted at 3 m spacing between sites marked for canarium and kava, with these species planted in the second year once shade has been established.[6] Early income is provided by plantain from the end of the first year, and kava from the end of the sixth year. Pacific kauri is a relatively slow-growing and self-pruning species with narrow crown, having high timber value. The area of plantain is reduced and that of kava increased after year 6, with plantain removed entirely at the end of year 12 (two six-year rotations) but kava continued until year 16 (three five-year rotations). Canarium trees are assumed to be felled for timber at an age of 30 years. The harvest age of Pacific kauri is uncertain, but probably about 40 years.

4 As noted by Thomson and Evans (2006), "An advantage of growing canarium nut in a polyculture … is the consequences of a canarium nut failure in a particular year can be minimized through production and sale of products from other species. Furthermore, there is a long waiting period (at least 7 years) before canarium nut plantations begin to provide commercial returns. Therefore, interplanting of crops that can provide more rapid returns such as root crops, banana, papaya, kava, *Barringtonia procera*, and *Terminalia catappa* may be necessary for cash-strapped farmers."

5 Thomson and Evans (2006) recommended a canarium tree spacing of 10 m × 10 m for nut production, but with distance within rows reduced to 2 m for combined timber and nut production.

6 According to Thomson and Evans (2006, p. 6), canarium can "tolerate 25–75% shade. Young plants are sensitive to full sun and ought to be planted under shade (at least 50% shade). After 3–4 years the level of shade may be progressively reduced, through thinning or ring-barking overstory plants."

FINANCIAL MODELS OF THE SELECTED AGROFORESTRY SYSTEMS

The financial models of these five agroforestry systems are presented as a collection of screenshots in Working Paper 9. In these models, summary spreadsheets reporting the species mixtures described above are presented as series of linked spreadsheets. Each agroforestry model includes a summary spreadsheet and related spreadsheets for the individual tree or crop species.

In general, the project lives adopted for the MSA models are relatively short. This is consistent with the approach adopted by Leslie (2013), and with the philosophy that a financial model only needs to cover sufficient years to demonstrate that a project or system is financially viable. Further, it is likely that landholders investing in agroforestry will have a relatively short planning horizon, in part due to uncertainty about the future prospects of their agroforestry investment.[7] In terms of the amount of financial support required by landholders to adopt agroforestry, the most critical time for support is likely to be the initial establishment phase.

For each agroforestry system model, there is passage of data between the summary sheet and the spreadsheets for individual species. The parameters considered most critical for financial performance and presented in the summary sheet are referenced in the individual species sheets. In turn, the annual net cash flows and annual labour requirements derived in the individual species sheets are referenced in the summary spreadsheet. For species with a schedule of yields over time rather than a single figure, a yield and management index or factor is included as a parameter in the summary sheet and referenced in the individual species sheets.

The spreadsheets for individual tree and crop species follow the general layout of parameter values, cash flow table (including capital outlays,

7 As noted by Dayananda et al. (2002, p. 119), the discount rate for private investments may be considered to consist of the risk-free discount rate, an average risk premium for the firm, and "*an additional risk factor* to account for the difference between the average risk and that of the proposed project". If agroforestry is perceived to have high risk, then a relatively short planning horizon is likely.

annual operating costs and project revenue) and then performance criteria. For annual crops, the cost and revenue data are simply repeated for a number of years, while for short-term but multi-year species, the cash flow data are repeated for each rotation. In this way a set of annual cash flows is obtained for the life of each species within the agroforestry system. The only financial performance criterion estimated in the spreadsheets for individual species is the net present value (NPV), bearing in mind that the primary interest is in the financial performance of the overall system, not particular components of it.

In the summary sheet the annual net cash flows for all species are combined, and an aggregate system NPV is derived for the overall agroforestry system. An aggregate labour requirement schedule is also derived. Also, the critical parameters—including product prices, product yield, wage rate and discount rate—are used in each sensitivity analysis, to derive a table of NPVs for expected value, and values 20% lower and 20% higher than the expected values. Examples are also provided of breakeven analysis and scenario analysis.

FINANCIAL ANALYSIS OF INDIVIDUAL SPECIES NOT INCLUDED IN THE MIXED-SPECIES AGROFORESTRY MODELS

In addition to the MSA system financial models, models have been developed for eight other individual species identified as being of high priority for growing in Fiji and Vanuatu. These are three timber species (whitewood, vesi and flueggia), three food crop tree species (avocado, Tahitian chestnut and sea almond) and two other food crop species (banana and taro). Summaries of estimated financial performance of these species are provided in Appendix A. The estimates have been made in Fijian dollars and the labour costs have been guided by the earlier table of work rates.

REFLECTIONS ON DEVELOPMENT OF THE MIXED-SPECIES AGROFORESTRY SYSTEMS

Arriving at the MSA systems described above was particularly challenging. Some of the difficult considerations are discussed below.

- Which species could be combined? For example, it would be inappropriate to combine two fast-growing large and spreading tree species such as canarium and tropical almond with intercropping because the intercrops would quickly be shaded out.
- How long could intercrops persist? Pineapple, cassava, plantain, kava and pigeonpea can be grown for more than one crop or cycle between fruit or nut trees, but usually not for the full planning horizon for these trees. Sometimes one or two intercrop cycles of 3–5 years will be appropriate.
- What are the shading needs of fruit and nut trees? Canarium is recognised to require shade for establishment. There are reports that cocoa also requires shading for establishment, but on Epi Island in Vanuatu cacao is being grown successfully without any initial shade crop.[8]
- How are agroforestry system designs best communicated to researchers and potential adopters? Probably some form of diagram would be preferable, but tables of land allocation within MSA systems contained in the summary spreadsheets were chosen as reasonably simple summaries of timing assumptions.

REFLECTIONS ON THE RESEARCH SITES CHOSEN FOR PROJECT ADP/2014/013

When developing the MSA financial models, some broadening from the initial focus areas for ACIAR project ADP/2014/013—abandoned sugarcane plantations in western Viti Levu and senile coconut plantations in Efate—was required. Sugar is still regarded by the Fiji Government as a priority industry, and steps are being taken to increase production efficiency to cope with a likely future sugar price decline. Possible measures include farm amalgamation to more financially viable units, reduced use of

8 The long-held view that rainforest tree species require initial shading was proved to be incorrect in the Community Rainforest Reforestation Program in tropical North Queensland in the 1990s. On the other hand, ring weeding while retaining tall surrounding vegetation (creating a 'light well') has been found to promote tree height growth in the large Conservation International agroforestry project in Ra Province, Viti Levu.

marginal sloping land, increased mechanisation, and refining raw sugar in Fiji (a major value-adding step). Also, while there appear to be large supplies of sugar in the international marketplace at present, the industry has a history of rapid price swings. Another issue found is that the Western District of Viti Levu—with its relatively low rainfall, dry winter, extensive cover of mission grass (similar to imperata grasslands) and frequent wildfires—is a difficult area to engage in agroforestry.

Recent evidence from a field trip indicates that the 'intermediate zone' in Ra Province (also within the Western Division of Viti Levu but more northerly), with slightly higher rainfall and more uniform rainfall distribution throughout the year, may be a better agroforestry site choice. This is also a sugar-growing area. The Nakauvadra community-based reforestation project of Conservation International, located in Ra Province, appears to have provided some valuable experience as to how agroforestry can succeed, some of the species mixtures having been planted five years ago.

In Vanuatu there is renewed interest in growing coconuts for a number of different products and diversifying from copra for which international prices are relatively low. Examples include certified organic coconut oil and new uses of coconut timber. Senile coconut plantations, where coco-lumber is not harvested, appear to be found mainly on islands where transport to markets is too costly. This situation was noted on a short visit to Epi, but is not such an issue on Efate which has been the project focus.

FURTHER RESEARCH NEEDS

Much has been achieved in ACIAR project ADP/2014/013 in understanding the opportunities and constraints and the potential financial performance of MSA systems in Fiji and Vanuatu. However, a one-year project with limited funding for fieldwork is restricted in how much it can achieve. Major concerns in the MSA system research component of the SRA include the small number of agroforestry systems examined, and the limited validation of the biophysical and financial parameters of the models. Further, it is clear that field trials and demonstration sites on agroforestry systems could promote the interest of researchers, farmers and the wider community about opportunities for expanded agroforestry development. Such trials and demonstrations would also provide a platform of refining and increasing confidence in financial models.

CONCLUSIONS

As part of ACIAR project ADP/2014/013, a few promising tree and crop mixtures have been designed for Fiji and Vanuatu, and the rationale for these mixtures has been examined. Prototype financial models have been developed for these mixtures, using adaptations of single-species financial models developed for priority tree and crop species, in a Microsoft Excel workbook platform.

Designing MSA systems for particular locations has proved a challenging task. It is logical to select regional and national priority tree species for forming the framework to these systems. Combining timber and fruit trees and other crops involves various decisions about spatial and temporal layout of species. Financial modules in Excel provide a starting point for developing MSA financial models, but adaptations of these modules are needed for particular applications.

This research has revealed that agroforestry is far more than throwing together a few species to be planted at the same time on the same land area. It typically requires much more complex design and management than mixed-species forestry. Consideration must be given to species–site matching, choosing compatible species and taking advantage of positive species interactions, sequential planting and harvesting, extent of post-harvest processing, and so on.

Many examples can be observed where promotion of monoculture and mixed-species timber plantations has created high interest and substantial planting activity by smallholders and even timber companies. Overly optimistic financial performance estimates have often accompanied extension efforts, and adverse publicity about unfavourable financial outcomes has provided a major setback to further planting. This experience suggests that considerable caution is needed to ensure the appropriateness of financial models for particular biological and socioeconomic circumstances.

The research undertaken in this project would appropriately be viewed as a demonstration of what can be done in financial analysis of mixed-species agroforestry in Fiji, Vanuatu and other Pacific island countries, and not as recommending any particular agroforestry systems for any particular locations. Considerably more research would need to be carried out before such recommendations would have credibility.

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APPENDIX A. FINANCIAL PERFORMANCE OF SPECIES NOT INCLUDED IN THE MULTI-SPECIES MODELS

Separate spreadsheet models have been prepared to estimate the financial performance of eight individual species as listed in the table below. These species have not been included in the MSA system financial models, but the spreadsheets are available as modules for further MSA system models. All these financial models relate to growing the species in Fiji, and the models are all based on Fiji data and calculated in Fiji dollars. The analyses are for a 1 ha planting, and an 8% discount rate is adopted.

The species

There is considerable interest in commercial production of whitewood, a fast-growing relatively low-density timber species, typically of good form, for export to countries where light-coloured timber is popular, including Japan. Vesi is better known commercially as merbau or kwila, and is a highly regarded timber species internationally, but it is slow growing and little information is available about plantation performance including harvest age. It can be grown on relatively dry sites. Poumuli or flueggea is a relatively fast-growing species, well suited for posts and poles (the former being modelled here), for which substantial research on plantation production has been carried out. Avocado is widely grown internationally as a vegetable food species. Polynesian (or Tahitian) chestnut and tropical almond both produce edible nuts, and are popular species in Pacific islands. Banana—a tree-like giant herb—is a highly important food species which crops from the first year; a four-year 'stool' life is assumed. Taro is a widely grown annual food crop. Three annual crops are assumed, after which a green manure crop may be required.

Financial performance

The species vary greatly in the estimated age at which they can be harvested and life of the stand. The net present values (NPVs) are positive for all species except for slow-growing vesi, for which a house pole harvest at age 20 and sawlog harvest at age 40 is assumed. NPV is particularly high for banana and taro (for which the labour requirement is also particularly high) and for avocado (for which the labour requirement before harvest age is relatively low). Banana and taro also have particularly high peak deficits, though only within the first year before a harvest. The land expectation value (LEV) or site value—the return from a perpetual rotation—is similar to the NPV for long-rotation species, but much higher for those with short rotations. Internal rate of return (IRR) is a relatively poor financial indicator for tree and crop species, particularly those with short rotations for which it can be meaninglessly high, but together with the NPV provides an indication that vesi might be worth growing if non-market (environmental) values are considered. The payback period is relatively short for flueggea (grown for strainer posts), avocado and the food crops.

Performance indicator	White-wood (*Endo-spermum medullosum*)	Vesi (*Intsia bijuga*)	Poumuli (*Flueggea flexuosa*)	Polynesian chestnut (*Inocarpus fagifer*)	Tropical almond (*Terminalia catappa*)	Avocado (*Persea americana*)	Banana (*Musa* spp.)	Taro (*Colocasia esculenta*)
'Project' life (years)	20	40	7	30	30	15	4	3
First harvest age (years)	20	20	7	6	3	6	1	1
NPV ($)	5,418	–2,054	1,505	11,734	5,084	48,175	43,337	20,160
LEV ($)	6,898	–2,153	3,614	13,028	5,645	70,353	163,556	97,785
IRR (%)	14.5	5	21	16.5	20	>25	>25	>25
Peak deficit ($)	2,957	4,022	1,709	4,135	1,321	2,983	4,765	5,516
Payback period (years)	20	Never	7	14	13	7	1	1
Labour, years 1–3 (days)	75	70	53	62	32	39	260	291

NPV = net present value; LEV = land expectation value; IRR = internal rate of return.

9. Screenshots of multi-species financial models and explanatory notes

Steve Harrison and Robert Harrison

Abstract

This working paper provides screenshots of the financial models of the five mixed-species agroforestry (MSA) models selected and described in Working Paper 8, together with notes to explain the structure and interpretation of these models. The Microsoft Excel workbook for each MSA system consists of a set of spreadsheets, including a first or summary sheet and a sheet for each individual species module. For each MSA system, the summary sheet contains the key parameter values of the system, and these are referenced by the spreadsheets for individual species. Conversely, the summary sheet for each system references the cash flow sequences for each individual species module to compile a summary of financial performance for the overall agroforestry system. Each species module is for a standard area unit of 1 ha, and all use a discount rate of 8%. Estimates of annual capital outlays, operating costs and revenue generated are presented for each individual species, to derive the annual net cash flows. Annual labour requirements are also estimated. The currency units are those for the country to which the MSA is best suited (Fiji dollars or Vanuatu vatu). In the summary sheet, the overall net present value (NPV) is computed for each species mixture. Sensitivity analysis, breakeven analysis and scenario analysis (where optimistic or pessimistic values for all parameters are considered simultaneously) are demonstrated. Notably, these have not been performed for individual tree and crop species, the financial analyses being designed to evaluate overall agroforestry systems, not individual components of them. Because the overall rotation length varies between MSA systems, the financial performance of all systems is compared on the basis of site value or land expectation value (LEV) (the sum of NPVs for a perpetual rotation). It is found that given the parameter values and other assumptions of the analyses, all the selected species mixtures would generate positive returns. NPV estimates per hectare for the five MSA systems in local currencies (Fiji dollars and Vanuatu Vatu) and Australian dollars are summarised in the following table. MSA species mixtures 2, 4 and 5 have very similar LEVs, considerably lower than those for mixtures 1 (dominated by mango) and 3 (dominated by sandalwood).

	AFM1	AFM2	AFM3	AFM4	AFM5
	Mango + cassava (Fiji)	**Breadfruit + pineapple + cassava (Fiji)**	**Citrus + sandalwood + pigeonpea (Fiji)**	**Cocoa + sandalwood + sweetpotato (Vanuatu)**	**Canarium + plantain + kava + Pacific kauri (Vanuatu)**
Project life (years)	15	20	20	30	40
NPV (local currency/ha)	98,136	47,105	230,473	2,693,918	2,775,365
NPV (A$/ha)	60,844	29,205	142,893	32,327	33,304
LEV (A$/ha)	88,855	37,182	181,925	35,894	34,911

EXPLANATORY NOTES ON THE AGROFORESTRY SYSTEM FINANCIAL MODELS

Structure and content of the linked spreadsheets in the agroforestry system workbooks

The Microsoft Excel workbook for each of the five selected agroforestry systems consists of a set of spreadsheets, including a first or summary sheet and a sheet for each species module. The summary sheets contain the key parameter values for each agroforestry system, and these are referenced by the spreadsheets for individual species. Conversely, summary sheets reference the cash flow sequences for each species module to compile a summary of financial performance for the overall agroforestry system.

The project life (or number of years for which the financial analysis is run) for agroforestry systems is kept as short as practicable. However, where timber species are included this requires that the analysis be extended up to the recommended harvest age of the species, e.g. 20 years for sandalwood and 40 year for Pacific kauri. Some of the year columns in the screenshots (mainly those where there is little change in the numbers) are hidden to ensure that the screenshot detail is not too small for convenient reading. Landscape orientation is used to improve readability of the screenshots.

Each species module is for a standard area unit of 1 ha, and all use a discount rate of 8%. The currency units are those for the country to which the agroforestry system is best suited (Fiji dollars or Vanuatu vatu).

Contents of the summary sheets

The top sections of the summary sheets list the tree and crop species in the mixtures, the years in which they are assumed to be grown, the areas for each species (percentage of a hectare), within and between row spacing, and yield and price parameters.

Below these data are sections on common parameters and on shared costs. The common parameters are the national minimum wage rate and the discount rate for calculating net present values (NPVs). Shared costs are overhead costs not attributable to a single species, e.g. expenditure on land leasing and land clearing, tools and equipment, and containers for use in harvesting food crops. These do not necessarily cover the full amounts of these overheads. It is probable that a farmer establishing agroforestry will already be engaged in agricultural activities and hence already have some plant and equipment. Hence the amounts allocated are designed to supplement existing items.

Documentation of a lease establishment fee in Fiji indicated the charge was about F$1,000/ha for high quality land in Viti Levu. This amount has been allocated under shared costs as part of the requirement for setting up an agroforestry project. No allowance has been made for annual land rentals, due to lack of information on these charges.

The next section presents the annual net cash flows for each species in the mixture. Where the percentage of area for a species changes between rotations of that species during the life of the agroforestry system, the different rotations are treated like different species when combining cash flows in the summary table. The common costs and annual cash flows for each species in the mixture are summed, and the aggregate NPV and overall internal rate of return (IRR) are calculated. This is followed by the stability analysis, i.e. the sensitivity analysis tables with respect to key parameters. Illustrations of breakeven and scenario analysis are also provided, but not for all agroforestry systems.

Allocating percentages of area

All agroforestry systems are evaluated on the basis of 1 ha planted area. When a species is included at its normal spacing within and between rows, it is regarded as taking 100% of planted area. However, the total area planted can be more than 100% of the 1 ha area if intercropping is included. In most mixtures the percentage of intercropping will decline during the life of the agroforestry system, as canopy closure of the tree component is approached.

Interpreting the internal rate of return

The concept of internal rate of return has a number of weaknesses, and this becomes apparent when examining performance of agroforestry species mixtures. IRR values are typically very high for the agroforestry systems modelled. These values are to a large extent a reflection of the cash flow pattern rather than of project financial performance. Where short-terms crops are included in the species mixture to ensure an early revenue flow, initial cash outflows are to some extent offset by revenue generated. The deliberate design of the cash flow pattern to achieve financial viability (low peak deficit) leads to IRR estimates which give an unrealistic impression of the rate of return on investment.

Yield levels versus yield indices

The yields of some tree and crop species are available as schedules of step functions, with yield changing in steps with tree or crop age over time. This is usually the case with fruit and nut trees. Also, for some tree species a number of distinct products are sold, a notable case being sandalwood, which can produce carving timber, heartwood for oil production, sapwood, fuelwood and edible nuts. In these cases, no single yield figure is available for sensitivity analysis, so instead a yield index is provided. This is referred to as a 'site and management index', and could also be used to reflect the impact of planting site quality.

Passing information between the summary sheet and sheets for individual species

The land allocation (percentage of area by year), yield and product price for each species and the wage rate and discount rate are recorded in the summary sheet, and referenced in the relevant sheets for the individual species. In turn, the cash flow series and annual labour requirements are calculated in the sheets for individual species, and referenced in the summary sheet to assemble the combined cash flow series, overall NPV and IRR, combined labour requirement, and financial stability analyses.

Information provided by the discounted cash flow and stability analysis

The aggregate NPVs for the aggregate annual net cash flows for an agroforestry system provide an estimate of how the grower's wealth would change by adopting this agroforestry system, taking into account the predicted capital outlays, operating costs and revenue generated over the project life. A positive NPV indicates that the project (i.e. agroforestry system) is financially viable. The pattern over time of the aggregate cash flows reveals whether the agroforestry system is financially feasible or affordable. The aggregate labour profile reveals for example whether the system is physically manageable by the farm family or whether labour hire is required.

Sensitivity analysis and other forms of stability analysis have have been performed for a few of the agroforestry systems. Notably, these have not been performed for individual tree and crop species. The financial analyses are designed to evaluate overall agroforestry systems, not individual components of them.

In the sensitivity analysis, values of the parameters expected to have the greatest impact on project payoff (taken to be the NPV) are adjusted by 20% in pessimistic and optimistic directions. This is achieved using the Data then What-If Analysis menu options in Excel. The parameters adjusted include crop yields, product prices and the wage and discount rates. Pessimistic values would include lower yields and product prices and higher labour costs (opportunity cost of farm family labour or wage rate for hired workers) and a higher discount rate (cost of capital).

Breakeven analysis involves using the Goal Seek facility in Excel to find the level of each parameter for which overall NPV is zero. It was found that breakeven analysis is not particularly useful for agroforestry systems containing three or four tree or crop species. Some species can generate enough revenue to carry low or zero financial performance of others. This can result in very low or even negative estimates of breakeven values.

Scenario analysis is similar to sensitivity analysis, but a more critical test of investment risk. The scenario manager in Excel is used to examine the impact on NPV when a number of parameters are concurrently assigned pessimistic or optimistic levels. 20% adjustments are again adopted. The pessimistic scenario is particularly useful for gaining an impression of what the financial performance would be like if there was a general downturn in prices, a destructive weather event or some other unforseen adverse circumstance.

Overall NPV estimates for the five agroforestry systems

	AFM1 Mango + cassava (Fiji)	AFM2 Breadfruit + pineapple + cassava (Fiji)	AFM3 Citrus + sandalwood + pigeonpea (Fiji)	AFM4 Cocoa + sandalwood + sweetpotato (Vanuatu)	AFM5 Canarium + plantain + kava + Pacific kauri (Vanuatu)
Project life (years)	15	20	20	30	40
NPV (local currency/ha)	98,136	47,105	230,473	2,693,918	2,775,365
NPV (A$/ha)	60,844	29,205	142,893	32,327	33,304
LEV (A$/ha)	88,855	37,182	181,925	35,894	34,911

The NPV estimates for the five multi-species agroforestry system are summarised in the above table, in local currencies and in Australian dollars. AFM2, AFM4 and AFM5 have very similar NPVs, considerably lower than those for AFM1 and AFM3. However, comparison is difficult because of variations in project life. To assist in the comparison, a new financial performance criterion, known as the site value or land expectation value (LEV), has been computed. This is a form of NPV, but computed for an 'infinite sequence of identical species mixtures'. In other words, it is the predicted financial return if the land were permanently committed to the particular mixture, and approximates the value of the land if permanently growing the mixture.

REFERENCE

Leslie D.M. 2013. Gross margins for selected fruit, vegetable and root crops for the sugar cane belt in Fiji. Secretariat of the Pacific Community, Suva.

SCREENSHOTS OF THE AGROFORESTRY SYSTEM FINANCIAL MODELS

AFM1: mango (*Mangifera indica*) + cassava (*Manihot esculenta*)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Q
1	**Summary sheet for mango and cassava MSA model**														
2															
3	**Tree or crop species mixture**	Area, year 1- 5	Area, yield 6-15	Row spacing (m)	Spacing within rows (m)	Planting density (sph)	Yield quantity or factor	Yield unit	Product price ($/kg)						
4	Mango (*Mangifera indica*)	100%	100%	9	9	123	1	Factor	1.75						
5	Cassava (*Manihot esculenta*)	55.56%	0%	1	0.5	16000	20000	kg/ha	0.9						
6															
7	**Shared costs**														
8	Land lease costs	1000			**Common parameters**										
9	Hand tools ($)	200			Wage rate (F$/day)		18.56								
10	Site clearing cost (F$)	37			Discount rate (%)		8%								
11	Knapsack sprayers ($)	300													
12	Containers - buckets, crates ($)	250													
13															
14	**Annual net cash flows, mango and cassava**														
15	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	15
16	Shared costs ($)	-1787													
17	Mango ($)	-978	-388	-1057	-1057	6193	12059	12059	12059	18464	18464	18464	18464	26851	26851
18	Cassava ($)	-1556	6580	6580	6580	6580	8136								
19	Aggregate net cash flow ($)	-4321	6191	5523	5523	12772	20195	12059	12059	18464	18464	18464	18464	26851	26851
20	Aggregate NPV ($)	122123													
21	Overall IRR ($)	150%													
22															
23	Labour requirement (days)														
24	Mango	5	6	39	39	26	102	102	102	149	149	149	149	161	161
25	Cassava	0	61	61	61	61	61								
26	Total labour requirement	5	67	100	100	87	163	102	102	149	149	149	149	161	161
27															

Summary sheet / Mango / Cassava / Sheet3

		Pessimistic	Expected	Optimistic	Breakeven
28	**Sensitivity analysis**				
29					**values**
30	Mango yield (factor)	0.8	1	1.2	-0.02
31		98152	122123	146093	
32	Mango price (F$)	1.4	1.75	2.1	0.08
33		96545	122123	147701	
34	Cassava yield (kg)	16000	20000	24000	-42700
35		114332	122123	129914	
36	Cassava price (F$)	0.72	0.9	1.08	-1.85
37		114137	122123	130109	
38	Wage rate (F$)	22.27	18.56	14.85	135.2
39		118237	122123	126009	
40	Discount rate (%)	9.60%	8%	6.40%	150%
41		107448	122123	139519	

Scenario Summary	Pessimistic	Expected	Optimistic
Changing Cells:			
G4	0.8	1.0	1.2
G5	16000	20000	24000
I4	1.4	1.75	2.1
I5	0.72	0.9	1.08
B8	22.27	18.56	14.85
B9	9.6%	8.0%	6.4%
Result Cells:			
B25	51849	122121	225364

In this model, mango is grown at 9 m × 9 m spacing over the whole planning horizon (of 15 years, following Leslie 2013). Cassava is grown on just over half the area, for the first five years. The yield and price parameters, and the wage and discount rates, are set out in the summary sheet. A yield factor rather than amount is used for mango, because yield changes over time as the trees grow. Cash flows are assembled for overhead cost and for the two species. The overall NPV is about F$120,000. Annual labour requirements are also reported for the two species, as well as their sum over time. The labour demand increases sharply when mango reaches harvest age.

Sensitivity, scenario and breakeven analyses are provided for this agroforestry system. Changes in parameter values of 20% in the pessimistic direction reveal that NPV is most sensitive to mango price, mango yield and discount rate (highlighted in red above). Breakeven yields and prices of mango and cassava are very low (one can finance the other), and very high wage and discount rates could be accommodated. Scenario analysis indicates that the NPV would be reduced to less than half if all six parameters simultaneously took pessimistic values.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	**Financial model for mango**																
2																	
3	Land area planted (ha)	1.0		Expected yield, yr 4 (kg/ha)			4500										
4	Yield factor	1.0		Expcted yield, yr 5-7 (kg/ha)			9000										
5	Row spacing (m)	9		Expected yield, yr 8-11 (kg/ha)			13500										
6	Spacing within rows (m)	9		Expected yield, yr 12-15 (kg/ha)			18750										
7	Number of trees	123		Transport cost ($/kg)			0.11										
8	Land preparation cost (F$/ha)	614		Labour requirement, year 0			5										
9	Planting materials ($/seedling)	2.2		Labour requirement, yr 1 (days)			6										
10	Planting materials, year 0 ($/ha)	272		Labour requirement, yrs 2-3 (days)			39										
11	Fertilizer, yr 1-3 ($/ha)	103		Labour requirement, yr 4 (days)			26										
12	Fertilizer, yr 4 ($/ha)	412		Labour requirement, yrs 5-7 (days)			102										
13	Fertilizer, yr 5-7 ($/ha)	516		Labour requirement, yrs 8-11 (days			149										
14	Fertilizer, yr 8-15 ($/ha)	619		Labour requirement, yr 12-15 (days			161										
15	Crop protection, yr 1 ($/ha)	174		Mango price (F$/kg)			1.75										
16	Crop protection, yr 2-3 ($/ha)	236		Wage rate (F$/day)			18.56										
17	Crop protection, yr 4-15 ($/ha)	299		Discount rate (%)			8%										
18																	
19	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20	Capital outlays ($)	885															
21	Fertilizer cost ($)		103	103	103	412	516	516	516	619	619	619	619	619	619	619	619
22	Crop protection cost ($)		174	236	236	299	299	299	299	299	299	299	299	299	299	299	299
23	Transport cost ($)					495	990	990	990	1485	1485	1485	1485	2063	2063	2063	2063
24	Labour cost ($)	93	111	718	718	476	1887	1887	1887	2759	2759	2759	2759	2982	2982	2982	2982
25	Total operating cost ($)	93	388	1057	1057	1682	3691	3691	3691	5161	5161	5161	5161	5962	5962	5962	5962
26	Production (kg/ha)					4500	9000	9000	9000	13500	13500	13500	13500	18750	18750	18750	18750
27	Revenue ($)	0	0	0	0	7875	15750	15750	15750	23625	23625	23625	23625	32813	32813	32813	32813
28	Net cash flow ($)	-978	-388	-1057	-1057	6193	12059	12059	12059	18464	18464	18464	18464	26851	26851	26851	26851
29	NPV($)	98136															
30																	
31	Annual labour requirement (days)	5	6	39	39	26	102	102	102	149	149	149	149	161	161	161	161

Scenario Summary 3 | Summary sheet | **Mango** | Cassava | Sheet3

	A	B	C	D	E	F	G
1	**Financial model for cassava**						
2							
3	Area planted (ha)	0.5556		Transport cost ($/kg)			0.022
4	Site and management factor	1.0		Labour requirement (dys/ha)			110
5	Distance between rows (m)	1.0		Cassava yield (kg/ha)			20000
6	Spacing within rows (m)	0.5		Wage rate (F$/day)			18.56
7	Number planted	11112		Quantity produced (kg)			11112
8	Land preparation cost ($/ha)	601		Cassava price (F$/kg)			0.9
9	Cost of planting materials ($/cutting)	0.11		Discount rate (%)			8%
10	Fertilizer cost ($/ha)	763					
11	Herbicide cost ($/ha)	112					
12							
13	Year	0	1	2	3	4	5
14	Land preparation cost ($)	334	334	334	334	334	
15	Cost of cuttings ($)	1222	1222	1222	1222	1222	
16	Fertiilizer and herbicide cost ($)		486	486	486	486	486
17	Transport cost ($)		244	244	244	244	244
18	Labour cost ($)		1134	1134	1134	1134	1134
19	Annual cost ($/ha)	1556	3421	3421	3421	3421	1865
20	Revenue ($)		10001	10001	10001	10001	10001
21	Net cash flow (%)	-1556	6580	6580	6580	6580	8136
22	NPV ($)	25774					
23							
24	Annual labour requirement (days)	0	61	61	61	61	61
25							

Scenario Summary 3 / Summary sheet / Mango / Cassava / Sheet3

AFM2: breadfruit (*Artocarpus altilis*) + pineapple (*Ananas comosus*) + cassava (*Manihot esculenta*)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	U	V
1	**Summary sheet for breadfruit, pineapple and cassava MSA model**															
2																
3	Tree or crop species mixture	Area, year 1-5	Area, year 6-10	Area, year 11-20	Row spacing (m)	Spacing within rows (m)	Planting density (sph)	Yield	Yield unit or factor	Product price ($/kg)						
4	Breadfruit (*Artocarpus altilis*)	90%	90%	90%	10	10	100	1	Factor	0.8						
5	Pineapple (*Ananas comosus*)	59.4%	10.8%	0%	0.825	0.3	40404	1	Factor	2						
6	Cassava (*Manihot esculenta*)	10%	10%	10%	1	0.5	20000	20000	kg/ha	0.9						
7																
8	**Shared costs**			**Common parameters**												
9	Land opportunity cost ($)	0		Wage rate (F$/day)		18.56										
10	Land access cost ($)	1000		Discount rate (%)		8%										
11	Site clearing labour ($)	37														
12	Additional hand tools ($)	200														
13	Containers - buckets & crates ($)	250														
14	Knapsack sprayer ($)	300														
15																
16	**Annual net cash flows - breadfruit, pineapple and cassava**															
17	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	19	20
18	Shared costs ($)	1787														
19	Breadfruit ($)	-521	-81	-81	-81	-493	1187	2867	4563	6243	6227	6227	6227	6227	6227	6243
20	Pineapple, first rotation ($)	-13883	-2959	5458	5947	5947	5491									
21	Pineapple, second rotation ($)						-2524	-538	992	1081	1081	998				
22	Cassava ($)	-280	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1464
23	Aggregate net cash flow ($)	-12897	-1856	6561	7051	6639	5338	3514	6739	8508	8493	8410	7411	7411	7411	7707
24	NPV ($)	47105														
25	IRR (%)	34%														

27	**Labour requirements (days)**															
28	Shared tasks	2														
29	Breadfruit	4	4	4	4	5	5	5	4	4	4	4	4	4	4	4
30	Pineapple, first rotation	15	52	55	58	58	53									
31	Pineapple, second rotation						3	10	10	11	11	10				
32	Cassava	0	11	11	11	11	11	11	11	11	11	11	11	11	11	11
33	Total labour requirement (days)	20	68	71	74	74	72	26	25	26	26	25	15	15	15	15
34																
35	**Sensitivity analysis**		Pessimistic	Expected	Optimistic											
36																
37	Breadfruit yield factor		0.8	1	1.2											
38			39666	47105	54543											
39	Breadfruit price ($)		0.64	0.8	0.96											
40			36478	47105	57731											
41	Pineapple yield factor		0.8	1	0.64											
42			41283	47105	36626											
43	Pineapple price ($)		1.6	2	2.4											
44			40760	47105	53450											
45	Cassava yield (kg/ha)		16000	20000	24000											
46			43657	47105	50553											
47	Cassava price ($/kg)		0.72	0.9	1.08											
48			43570	47105	50639											
49	Wage rate ($)		22.27	18.56	14.85											
50			45535	47105	48675											
51	Discount rate ($)		9.6%	8.0%	6.4%											
52			39523	47105	56322											

This model involves growing breadfruit intercropped with pineapples on 90% of the area, and cassava on the other 10%. There are two five-year rotations of pineapples, the first occupying about 60% of the hectare and the second about 10%, as the breadfruit trees grow and their crown area increases. The labour demand is found to be high during the first pineapple rotation, but relatively low thereafter. Sensitivity analysis has been performed for this agroforestry system, and reveals that NPV is most sensitive to breadfruit price and yield, and the discount rate. Cassava yield and price and the wage rate have little effect on NPV.

	A	B	C	D	E	F	G	H	I
1	**Breadfruit financial model**								
2									
3	Area planted (ha)	1.0		Yield, year 5 (kg/tree)					30
4	Site and management factor	1.0		Yield, year 6 (kg/tree)					60
5	Distance between rows (m)	10		Yield, year 7 (kg/tree)					90
6	Spacing within rows (m)	10		Yield, year 8 on (kg/tree)					120
7	Number of trees grown	100		Outlay on harvesting poles ($)					100
8	Hole digging and planting time (mins/tree)	15		Planting stock, delivered ($/each)					0.55
9	Initial fertilizing and/or mulching (mins/tree)	2		Mixed fertilizer cost ($/tree)					4
10	Fertilizer application time (mins/tree)	4		Labour cost ($/day)					18.56
11	Ring weeding, year 1-3, 3 rounds	21		Harvesting, grading and packaging ($/kg)					0.14
12	Ring weeding, years 4-6, 2 rounds	14		Transport ($/kg)					0.10
13	Pruning labour yrs 4-8 (mins/tree)	6		Breadfruit price (F$/kg)					0.80
14	Pruning labour yrs 9-20 (mins/tree)	10		Income tax rate (%)					0%
15	Tree maintenance yr 7 on (mins/tree)	10		Discount rate (%)					8%
16									

19	**Capital outlays**														
20	Planting stock ($)	55													
21	Chemical fertilizer and mulch ($)	400													
22	Hold digging, fertilizing and planting ($)	66													
23	Total capital outlays ($)	521													
24															
25	**Operating costs**														
26	Weed control ($)		81	81	81	54	54	54							
27	Fertilizer and/or mulch cost ($)					400	400	400	400	400	400	400	400	400	400
28	Fertilizing and/or mulching labour ($)					15	15	15	15	15	15	15	15	15	15
29	Pruning labour ($)					23	23	23	23	23	39	39	39	39	23
30	Other tree protection & maintenance ($)								39	39	39	39	39	39	39
31	Harvesting, grading and packing ($)						420	840	1260	1680	1680	1680	1680	1680	1680
32	Transport ($)						300	600	900	1200	1200	1200	1200	1200	1200
33	Total operating costs ($)		81	81	81	493	1213	1933	2637	3357	3373	3373	3373	3373	3357
34															
35	**Project revenue**														
36	Breadfruit sales ($)						2400	4800	7200	9600	9600	9600	9600	9600	9600
37															
38	Annual net cash flow ($)	-521	-81	-81	-81	-493	1187	2867	4563	6243	6227	6227	6227	6227	6243
39	Net present value (NPV, $)	32915													
40															
41	Annual labour requirement (days)	4	4	4	4	5	5	5	4	4	4	4	4	4	4

	A	B	C	D	E	F	G	H
1	**Financial model for pineapple production**							
2								
3	Area planted (ha)	0.594		Transport cost ($/kg)				0.17
4	Yield or management factor	1.0		Labour requirement, year 0 (days/ha)				14.85
5	Distance between rows (m)	0.825		Labour requirement, year 1 (days/ha)				52.27
6	Spacing within rows (m)	0.3		Labour requirement, year 2 (days/ha)				55.24
7	Number planted	24000		Labour requirement, year 3 (days/ha)				58.21
8	Land preparation cost ($/ha)	686		Labour requirement, year 4 (days/ha)				58.21
9	Cost of planting materials ($/sucker)	0.55		Labour requirement, year 5 (hrs/ha)				53.46
10	Planting materials ($/ha)	13200		Pineapple yield, yr 2 & yr 5 (kg/ha)				7500
11	Fertilizer, year 1 ($/ha)	1891		Pineapplie yield, yr 3 & yr 4 (kg/ha)				8000
12	Fertilizer, year 2-5 ($/ha)	1392		Pineapple price ($/kg)				2.00
13	Herbicide, fungicide & insecticide, yr 1-5 ($/ha)	1457		Wage rate (F$/day)				18.56
14	Pineapple yield, yr 2 & 5 (kg/ha)	7500		Discount rate (%)				8%
15	Pineapple yield, yrs 3 & 4 (kg/ha)	8000						
16								
17	Year	0	1	2	3	4	5	
18	Land preparation cost ($)	408						
19	Cost of planting materials ($)	13200						
20	Fertilizer cost ($)		1123	827	827	827	827	
21	Herbicide, fungicide & insecticide ($)		865	865	865	865	865	
22	Transport cost ($)			735	784	784	735	
23	Labour cost ($)	276	970	1025	1080	1080	992	
24	Annual cost ($)	13883	2959	3452	3557	3557	3419	
25	Production (kg/ha)			4455	4752	4752	4455	
26	Revenue ($)			8910	9504	9504	8910	
27	Net cash flow ($)	-13883	-2959	5458	5947	5947	5491	
28	NPV ($)	886						
29								
30	Annual labour requirement (days)	15	52	55	58	58	53	

	A	B	C	D	E	F	G	H	I	J	K	L	M	U	V
1	**Financial model for cassava**														
2															
3	Area planted (ha)	0.1		Herbicide cost ($/ha)			112								
4	Site or management factor	1.0		Transport cost ($/kg)			0.022								
5	Distance between rows (m)	1		Labour requirement (dys/ha)			110								
6	Spacing within rows (m)	0.5		Cassava yield (kg/ha)			20000								
7	Number planted	2000		Quantity produced (kg)			2000								
8	Land preparation cost ($/ha)	601		Cassava price (F$/kg)			0.9								
9	Cost of planting materials ($/cutting)	0.11		Wage rate (F$/day)			18.56								
10	Fertilizer cost ($/ha)	763		Discount rate (%)			8%								
11															
12	Year	0	1	2	3	4	5	6	7	8	9	10	11	19	20
13	Land preparation cost ($)	60	60	60	60	60	60	60	60	60	60	60	60	60	
14	cost of cuttings ($)	220	220	220	220	220	220	220	220	220	220	220	220	220	
15	Fertilizer and herbicide cost ($)		88	88	88	88	88	88	88	88	88	88	88	88	88
16	Transport cost ($)		44	44	44	44	44	44	44	44	44	44	44	44	44
17	Labour cost ($)		204	204	204	204	204	204	204	204	204	204	204	204	204
18	Annual costs ($)	280	616	616	616	616	616	616	616	616	616	616	616	616	336
19	Revenue ($)		1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
20	Net cash flow (%)	-280	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1464
21	NPV ($)	11407													
22															
23	Annual labour requirement (days)		11	11	11	11	11	11	11	11	11	11	11	11	11

AFM3: citrus (*Citrifolia sinensis*) + sandalwood (*Santalum yasi*) + pigeonpea (*Cajanus cajan*)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	U	V
1	**Summary sheet for citrus, sandalwood and pigeon pea**															
2																
3	Tree or crop species	Area, yr 1-3	Area, yr 4-6	Area, yr 7-20	Row spacing (m)	Spacing within rows (m)	Planting density (sph)	Yield	Yield unit	Product price	Price unit					
4	Sweet orange *Citrifolia sinensis*)	100%	100%	100%	7	6	238	1.0	Factor	1.5	$/kg					
5	Sandalwood (*Santalum yasi*)	100%	100%	100%	7	6	238	1.0	Factor	1.0	Index					
6	Pigeon Pea (*Cajanus cajan*)	88%	45%	0%	0.7	0.2	71429	2000	kg	5	$/kg					
7																
8	**Shared costs**				**Common parameters**											
9	Land lease costs ($)	1000			Wage rate (F$)		18.56									
10	Hand tools ($)	200			Discount rate (%)		8%									
11	Site clearing costs ($)	37														
12	Knapsack sprayer ($)	300														
13	Containers - buckets, crates ($)	250														
14	Covered concrete drying area ($)	2000														
15																
16	**Annual net cash flows - citrus, sandalwood and pigeon pea**															
17	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	19	20
18	Shared costs ($)	-3787														
19	Citrus ($)	-1217	-3444	-1891	-1891	11772	18592	25393	25338	25338	25338	25338	25338	25338	25338	25338
20	Sandalwood ($)	-1388	-378	-378	-378	-301	-201	-155	-62	-62	-62	-155	-62	-62	-62	249906
21	Pigeon pea, first rotation ($)	-1101	6776	6514	6514											
22	Pigeon pea, second rotation ($)				-563	3465	3331	3331								
23	Aggregate net cash flow ($)	-7493	2954	4245	3682	14936	21722	28570	25276	25276	25276	25183	25276	25276	25276	275244
24	Aggregate NPV ($)	230473														
25	Overall IRR (%)	83%														
26																
27	**Annual Labour requirement (days)**															
28	Citrus	5	19	42	42	34	41	49	52	52	52	52	52	52	52	52
29	Sandalwood	18	15	15	15	11	11	17	3	3	3	8	3	8	3	153
30	Piigeon pea, first rotation	14	64	78	78											
31	Piigeon pea, second rotation				7	33	40	40								
32	Total labour requirement (days)	37	98	135	142	77	92	105	55	55	55	60	55	60	55	205

In this agroforestry system, a citrus species (as a host crop) and sandalwood are grown together until sandalwood can be harvested at year 20. Two three-year rotations of pigeonpea are also grown, as a cash crop, nitrogen fixer and short-term host for sandalwood, the area for pigeonpea being reduced in the second rotation. The labour requirement is relatively high during the pigeonpea rotations, and particularly high when the sandalwood is harvested.

	A	B	C	D	E	F	G	H	I	J	K	L	M	U	V
1	**Citrus (sweet orange) financial model**														
2															
3	Area planted (ha)	1.0		Cost of herbicide & fungicide, yrs 1-3 ($/ha)				653							
4	Site and management factor	1.0		Cost of herbicide & fungicide, yr 4 on ($/ha)				833							
5	Distance between rows (m)	7		Transport cost ($/kg)				0.11							
6	Spacing within rows (m)	6		Yield, yr 4 (kg/ha)				10000							
7	Planting density (plants/ha)	238		Yield, yr 5 (kg/ha)				15000							
8	Land preparation cost ($/ha)	862		Yield, yr 6 on (kg/ha)				20000							
9	Cost of grafted plants ($/unit)	1.1		Fruit price ($/kg)				1.5							
10	Cost of fertilizer, yr 1 ($/ha)	2438		Wage rate (F$)				18.56							
11	Cost of fertilizer, yr 2,3 ($/ha)	458		Discount rate ($)				8%							
12	Cost of fertiliizer, yr 4 on	664													
13															
14	Year	0	1	2	3	4	5	6	7	8	9	10	11	19	20
15	Land preparation cost ($)	862													
16	Cost of grafted plants ($)	262													
17	Fertiliizer cost ($)		2438	458	458	664	664	664	664	664	664	664	664	664	664
18	Herbicide and fungicide cost ($)		653	653	653	833	833	833	833	833	833	833	833	833	833
19	Transport cost ($)					1100	1650	2200	2200	2200	2200	2200	2200	2200	2200
20	Area-related labour reqt (dys/ha)	5	19	42	42	26	29	34	34	34	34	34	34	34	34
21	Yield-related labour reqt (days/ha)					8	12	15	18	18	18	18	18	18	18
22	Annual labour requirement (days/ha)	5	19	42	42	34	41	49	52	52	52	52	52	52	52
23	Labour cost ($)	93	353	780	780	631	761	909	965	965	965	965	965	965	965
24	Production (kg/ha)					10000	15000	20000	20000	20000	20000	20000	20000	20000	20000
25	Revenue ($)					15000	22500	30000	30000	30000	30000	30000	30000	30000	30000
26	Net cash flow ($)	-1217	-3444	-1891	-1891	11772	18592	25393	25338	25338	25338	25338	25338	25338	25338
27	NPV ($)	161418													
28															
29	Annual labour requirement (days)	5	19	42	42	34	41	49	52	52	52	52	52	52	52

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	U	
1	**Sandalwood financial model (*S. yasi or hybrid*)**																	
2																		
3	**Physical parameters**			Pruning labour, yr 5 (mins/tree)						3		**Sandalwood product partitioning and revenue**						
4	Area planted to sandalwood (ha)	1.0		Pruning labour, yr 10 (mins/tree)						6								
5	Site and management factor	1.0		Tree maintenance, yr 7 on (mins/tree)						4		Total yield (kg/tree)				140		
6	Price factor	1.0		Tree felling, bucking & debarking, yr 20 (hrs/tree)						0.75		Heartwood yield (kg/tree)				31		
7	Distance between rows (m)	5		Sapwood chipping time, yr 20 (hrs/tree)						0.75		Carving timber (kg/tree)				8		
8	Spacing within rows (m)	5		Root cleaning and chipping labour, yr 20 (hrs/tree)						1.5		Heartwood for oil (kg/tree)				23		
9	Number of trees	400		Harvest year						20		Sapwood yield (kg/tree)				109		
10	Hole digging and planting (mins/seedling)	10										Fuelwood yield (kg/tree)				0		
11	Fertilizer rate at planting (grams/seedling)	100		**Financial parameters**								S'wood seed yield (kg/tree)				1.0		
12	Fertilizing/ mulching at planting (mins/seedling)	5		Seedling cost ($/seedling)						2		Craftwood price ($/kg)				30		
13	Watering at planting (mins/seedling)	5		NPK mixed fertilizer cost ($/kg)						2.5		Heartwood price ($/kg)				20		
14	Tree mortality rate after at planting (%)	20%		Contract root lifting, yr 20 ($/tree)						10		Sapwood price ($/kg)				1		
15	Infilling time (mins/tree)	6		Timber haulage to covered area, at house ($/tree)						10		Fuelwood price ($/m^3)				0		
16	Weed control labour, yrs 1-3 (mins/tree)	15		Commission on sandalwood sales (%)						20%		Seed price ($/kg)				4		
17	Weed control labour, yrs 4-6 (mins/tree)	10		Income tax rate (%)						0%		Revenue at harvest age ($/tree)				811		
18	Fertilizer rate, years 1-4 (gm/tree)	100		Wage rate ($/person/day)						18.56		Total revenue, all trees ($)				324200		
19	Fertilizer labour, years 1-4 (mins/tree)	3		Discount rate (%)						8%		Revenue less commission ($)				259360		
20																		
21	**Annual cash flows**																	
22	Year ->	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	19	20
23	**Capital outlays**																	
24	Planting materials ($)	800																
25	Chemical fertilizer and mulch ($)	100																
26	Planting and related tasks ($)	309																
27	Infilling cost ($)	179																
28	Total capital outlays ($)	1388																
29																		
30	**Operating costs**																	
31	Weed control labour ($)		232	232	232	155	155	155										
32	Fertilizing or mulch cost ($)		100	100	100	100												
33	Fertilizing labour cost ($)		46	46	46	46												
34	Pruning cost ($)						46					93						
35	Later tree maintenance cost ($)								62	62	62	62	62	62	62	62	62	62
36	Tree felling, bucking & debarking ($)																	696
37	Root uplifting cost ($)																	4000
38	Sapwood chipping labour cost ($)																	696
39	Cost of transport to covered area ($)																	4000
40	Total operating costs ($)		378	378	378	301	201	155	62	62	62	155	62	62	62	62	62	9454
41																		
42	**Project revenue**																	
43	Farm-gate sales revenue ($)																	259360
44	Net cash flow ($)	-1388	-378	-378	-378	-301	-201	-155	-62	-62	-62	-155	-62	-62	-62	-62	-62	249906
45	NPV ($)	50447																
46																		
47																		
48	Annual labour requirement (days)	18	15	15	15	11	11	17	3	3	3	8	3	8	3	8	3	153

	A	B	C	D	E	F	G
1	**Pidgeon pea financial model**						
2							
3	Area planted (ha)	88%		Yield of dry seed, year 1 (kg/ha)			2000
4	Site and management factor	1.0		Yield of dry seed, year 2 (kg/ha)			2000
5	Distance between rows (m)	0.7		Yield of dry seed, year 3 (kg/ha)			2000
6	Spacing within rows (m)	0.2		Labour requirement, year 0 (days)			14
7	Planting density (plants/ha)	71429		Labour requirement, year 1 (days)			64
8	Land preparation cost ($/ha)	774		Labour requirement, year 2 (days)			78
9	Cost of seed ($/ha)	179		Labour requirement, year 3 (days)			78
10	Cost of fertilizer ($/ha)	424		Yield (kg dry seed/ha)			2000
11	Cost of fungicide and insecticide ($/ha)	95		Dry seed price ($/kg)			5
12	Transport cost ($/kg)	0.22		Wage rate (F$)			18.56
13	Standard yield (kg/ha)	2750		Discount rate ($)			8%
14							
15							
16	Year	0	1	2	3		
17	Land preparation ($)	681					
18	Seed for planting ($)	157					
19	Fertiliizer cost ($)		373	373	373		
20	Fungicide and insecticide cost ($)		83	83	83		
21	Transport cost ($)		387	387	387		
22	Labour cost ($)	262	1180	1443	1443		
23	Quantity sold (kg)		1760	1760	1760		
24	Revenue ($)		8800	8800	8800		
25	Net cash flow ($)	-1101	6776	6514	6514		
26	NPV ($)	15929					
27							
28	Labour (dys/ha)	14	64	78	78		

AFM4: cocoa (*Theobroma cacao*) + sandalwood (*Santalum austrocaledonicum* or hybrid) + sweetpotato (*Ipomoea batatas*)

	A	B	C	D	E	F	G	H	I	J	K	L	M	U	V	W	AF
1	**AM4 - Summary sheet for cacao + sandalwood + sweet potato**																
2																	
3	Tree or crop species	Area, year 1-4	Area, year 5-20	Area, yr 21-30	Row spacing (m)	Spacing within rows (m)	Planting density (sph)	Product yield	Yield quantity unit	Product price (vt)	Price unit						
4	Cacao (*Theobroma cacao*)	100%	100%	100%	5	5	400	1	Factor	400	vt/kg DFCB						
5	Sandalwood (*S. austrocaledonicum*)	100%	100%	0%	5	5	400	1	Factor	1	Index						
6	Sweet potato (*Ipomoea batatas*)	12%	0%	0%	1	0.5	20000	12000	kg/ha	75	vt/kg						
7																	
8	**Shared costs**				**Common parameters**												
9	Land lease establishment fee (vt/ha)	Not known			Wage rate (VT 1000)		1400										
10	Land annual rental cost (vt/ha)	Not known			Discount rate (%)		8%										
11	50% of drying area construction cost (vt)	83300															
12	Cost of knapsack sprayer (vt)	24990			DFCB means dried fermented cacao beans												
13	Cost of second-hand light chainsaw (vt)	16660															
14	Sundry tools (vt 1000)	10340															
15	Crates and buckets (vt 1000)	10															
16	Land clearing labour (days/ha)	6															
17	Land clearing cost (vt 1000/ha)	8400															
18	Chainsaw fuel, oil and maintenance (vt)	Not known															
19																	
20	**Annual net cash flows - cacao, sandalwood and sweet potato**																
21	Year	0	1	2	3	4	5	6	7	8	9	10	11	19	20	21	30
22	Shared costs ($)	-143706															
23	Cacao ($)	-74480	-22613	-22613	-22613	-20280	-80876	-45443	-16009	9924	35857	61791	61791	61791	61791	61791	61791
24	Sandalwood ($)	-79535	-26170	-26170	-26170	-20337	-15167	-11667	-4667	-4667	-4667	-11667	-4667	-4667	12837773		
25	Sweet potato ($)	-21407	61347	61347	61347	82250											
26	Aggregate net cash flow (vt)	-319128	12564	12564	12564	41633	-96043	-57109	-20676	5257	31191	50124	57124	57124	12899564	61791	61791
27	NPV (vt)	2693918															
28	IRR (%)	21%															
29																	

Summary sheet / Cacao / Sandalwood / Sweet potato / Sheet2 / Sheet3

30	**Labour requirement (days)**																
31	Cacao	10	7	7	6	4	19	23	25	29	33	38	38	38	38	38	38
32	Sandalwood	18	15	15	15	11	11	17	3	3	3	8	3	3	153		
33	Sweet potato	3	13	13	13	10											
34	Total labour requirement (days)	31	34	34	34	25	29	40	28	32	37	46	41	41	191	38	38
35																	
36	**Sensitivity analysis**		Pessimistic	Expected	Optimistic												
37																	
38	Cacao yield index		0.8	1	1.2												
39			2511558	2693918	2867825												
40	Cacao price (vt/kg)		320	400	480												
41			2448036	2693918	2939801												
42	Sandalwood yield index		0.8	1	1.2												
43			2121185	2693918	3266652												
44	Sandalwood price index		0.8	1	1.2												
45			2121185	2693918	3266652												
46	Sweet potato yield (kg/ha)		14000	17500	21000												
47			2750357	2849125	2947892												
48	Sweet potato price (vt/kg)		60	75	90												
49			2622376	2693918.4	2765460												
50	Wage rate (vt/day)		1680	1400	1120												
51			2563800	2693918.4	2824037												
52	Discount rate (%)		9.60%	8%	6.40%												
53			1930638	2693918	3736207												

In this model, loosely based on a site visited on Epi Island in Vanuatu, cocoa and sandalwood are grown together, with the sandalwood harvested at year 20 and the cocoa continued until year 30. Sweetpotato is grown as a cash crop, and to aid weed control, for the first four years. The NPV is particularly high (about 2.7 million vatu, or A$32,000, over the 30 years). This is mainly due to the very high value of sandalwood. Sandalwood has a quite low labour requirement throughout the rotation, except for an extremely high harvest and post-harvest processing labour requirement. NPV is highly sensitive to the discount rate and sandalwood yield and price.

	A	B	C	D	E	F	G	H
1	**Cacao Production Financial Model**							
2								
3	**Physical parameters**							
4	Area planted (ha)	1.0		Cacao tree yield (kg DFCB/tree), yr 7				0.6
5	Site and management index	1.0		Cacao tree yield (kg DFCB/tree), yr 8				0.8
6	Distance between rows (m)	5		Cacao tree yield (kg DFCB/tree), yr 9				1
7	Distance within rows (m)	5		Cacao tree yield (kg DFCB/tree), yr 10 on				1.2
8	Number of trees	400		Pod collection labour (mins/kg DFCB)				10
9	Hole digging time (mins/tree)	10		Wet bean extraction (mins/kg DFCB)				12
10	Fertilizing or mulching at planting (mins/tree)	2		Bean fermentation, drying (mins/kg DFCB)				4
11	Ringweeding, year 1-3, 3 rounds (mins/tree)	6						
12	Ringweeding, year 3-6, 3 rounds (mins/tree)	3		**Financial parameters**				
13	Fertilizer quantity, yr 1-4 (kg/tree)	0.4		Cost of 4 harvesting baskets (vt)				2500
14	Fertilizer rate, year 5 on (kg/tree)	1.33		Cost of 2 fermetation boxes (vt)				5000
15	Fertilizing labour time, yrs 1-4 (mins/tree)	2		Cost of sacks for selling beans (vt/bag)				200
16	Fertilizing labour time, yr 5 on (mins/tree)	3		Cost of seedlings (vt/seedling)				83
17	Pruning labour, yr 5 on (mins/tree)	6		Mixed NPK fertilizer price (vt/kg)				83
18	Pesticide/disease control chems, yr 5 on (mls/tree)	5		Pest and disease control chemicals (vt/litre)				16660
19	Pesticide appn labour, yr 5 on (mins/tree)	5		Bean price (vt/kg dried beans)				400
20	Cacao tree yield (kg DFCB/tree), yr 5	0.2		Wage rate (vt/day)				1400
21	Cacao tree yield (kg DFCB/tree), yr 6	0.4		Discount rate (%)				8%
22								

	A	B	C	D	E	F	G	H	I	J	K	L	AD	AE	AF
23	**Annual cash flow table**														
24	Year	0	1	2	3	4	5	6	7	8	9	10	28	29	30
25	Capital outlays														
26	Hole digging and planting (vt)	28000													
27	Seedling cost (vt)	33200													
28	Fertilizer cost (vt)	13280													
29	Harvesting baskets (vt)						2500								
30	Fermentation boxes (vt)						5000								
31	Sacks for selling beans (vt)						2000								
32	Total capital outlays (vt)	74480					9500								
33															
34	Operating costs														
35	Weed control (vt)		7000	7000	7000	3500	3500	3500							
36	Fertilizer cost (vt)		13280	13280	13280	13280	44156	44156	44156	44156	44156	44156	44156	44156	44156
37	Fertilizer labour (vt)		2333	2333	2333	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
38	Pruning cost, yr 5 on (vt)						7000	7000	7000	7000	7000	7000	7000	7000	7000
39	Pest and disease control chemicals, yr 5 on (vt)						33320	33320	33320	33320	33320	33320	33320	33320	33320
40	Pest control labour, yr 5 on (vt)						5833	5833	5833	5833	5833	5833	5833	5833	5833
41	Pod collection labour (vt)						2333	4667	7000	9333	11667	14000	14000	14000	14000
42	Wet bean extraction (vt)						2800	5600	8400	11200	14000	16800	16800	16800	16800
43	Wet bean fermentation and drying (vt)						933	1867	2800	3733	4667	5600	5600	5600	5600
44	Total operating costs (vt)		22613	22613	22613	20280	103376	109443	112009	118076	124143	130209	130209	130209	130209
45															
46	Sales revenue														
47	Cocoa yield (kg dried beans/tree)						0.20	0.40	0.60	0.80	1.00	1.20	1.20	1.20	1.20
48	Revenue from bean sales (vt)						32000	64000	96000	128000	160000	192000	192000	192000	192000
49															
50	Annual net cash flow ($)	-74480	-22613	-22613	-22613	-20280	-80876	-45443	-16009	9924	35857	61791	61791	61791	61791
51															
52	**Project performance criteria**														
53	Net present value ($)	92242													
54	Internal rate of return (%)	10.6%													
55	Annual labour requirement (days)	10	7	7	6	4	19	23	25	29	33	38	38	38	38

	A	B	D	I	K	O
1	**Sandalwood financial model (*S. austrocaledonicum*)**					
2						
3	**Physical parameters**		Pruning labour, yr 5 (mins/tree)	3	**Sandalwood product partitioning and revenue**	
4	Area planted to sandalwood (ha)	1.0	Pruning labour, yr 10 (mins/tree)	6		
5	Site and management factor	1.0	Tree maintenance, yr 7 on (mins/tree)	4	Total yield (kg/tree)	140
6	Price factor	1.0	Tree felling, bucking & debarking, yr 20 (hrs/tree)	0.75	Heartwood yield (kg/tree)	31
7	Distance between rows (m)	5	Sapwood chipping time, yr 20 (hrs/tree)	0.75	Carving timber (kg/tree)	8
8	Spacing within rows (m)	5	Root cleaning and chipping labour, yr 20 (hrs/tree	1.5	Heartwood for oil (kg/tree)	23
9	Number of trees	400	Harvest year	20	Sapwood yield (kg/tree)	109
10	Hole digging time (mins/tree)	10			Fuelwood yield (kg/tree)	0
11	Fertilizer rate at planting (grams/tree)	100	**Financial parameters**		S'wood seed yield (kg/tree)	1.0
12	Planting fertilizing/ mulching time (mins/tree)	5	Seedling cost (vt/seedling)	103	Craftwood price (vt/kg)	1551
13	Planting and watering time (mins/seedling)	5	NPK mixed fertilizer cost (vt/kg)	129	Heartwood price (vt/kg)	1034
14	Tree mortality rate after at planting (%)	20%	Contract root lifting, yr 20 (vt/tree)	500	Sapwood price (vt/kg)	50
15	Infilling time (mins/tree)	6	Timber haulage to covered area, at house (vt/tre	500	Fuelwood price (vt/m^3)	0
16	Weed control labour, yrs 1-3 (mins/tree)	15	Commission on sandalwood sales (%)	20%	Seed price (vt/kg)	200
17	Weed control labour, yrs 4-6 (mins/tree)	10	Income tax rate (%)	0%	Revenue at harvest age (vt/tree)	41711
18	Fertilizer rate, years 1-4 (gm/tree)	100	Wage rate (vt/person/day)	1400	Total revenue, all trees (vy)	16684300
19	Fertilizer labour, years 1-4 (mins/tree)	3	Discount rate (%)	8%	Revenue less commission (vt)	13347440
20						

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O			
21	**Annual cash flows**																	
22	Year ->	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	19	20
23	**Capital outlays**																	
24	Planting materials (vt)	41360																
25	Chemical fertilizer and mulch (vt)	5170																
26	Planting and related tasks (vt)	23333																
27	Infilling cost (vt)	9672																
28	Total capital outlays (vt)	79535																
29																		
30	**Operating costs**																	
31	Weed control labour (vt)		17500	17500	17500	11667	11667	11667										
32	Fertilizing or mulch cost (vt)		5170	5170	5170	5170												
33	Fertilizing labour cost (vt)		3500	3500	3500	3500												
34	Pruning cost (vt)						3500					7000						
35	Later tree maintenance cost (vt)								4667	4667	4667	4667	4667	4667	4667	4667	4667	4667
36	Tree felling, bucking and debarking (vt)																	52500
37	Root uplifting cost (vt)																	200000
38	Sapwood chipping labour cost (vt)																	52500
39	Cost of transport to covered area (vt)																	200000
40	Total operating costs (vt)	0	26170	26170	26170	20337	15167	11667	4667	4667	4667	11667	4667	4667	4667	4667	4667	509667
41																		
42	**Project revenue**																	
43	Farm-gate sales revenue (vt)																	13347440
44	Net cash flow (vt)	-79535	-26170	-26170	-26170	-20337	-15167	-11667	-4667	-4667	-4667	-11667	-4667	-4667	-4667	-4667	-4667	12837773
45	NPV (vt)	2548235																
46																		
47	Annual labour requirement (days)	18	15	15	15	11	11	17	3	3	3	8	3	8	3	8	3	153

	A	B	C	D	E	F	G
1	**Sweet potato financial model**						
2							
3	Area planted (ha)	0.12		Insecticide cost (vt/ha)			17061
4	Site or management factor	1.0		Transport cost (vt/kg)			4
5	Row spacing (m)	1.0		Labour requirement, yr 0			3
6	Spacing within rows	0.5		Labour requirement, yr 1-3			13
7	Number of plants	2400		Labour requirement, yr 4			10
8	Land preparation cost (vt/ha)	31051		Annual labour required (days/ha)			12.6
9	Tuber cutting price (vt/unit)	5.7		Sweet potato yield (kg/ha)			12000
10	Cost of tuber cuttings (vt)	13649		Production (kg)			1440
11	Tuber cuttings (no/ha)	20000		Sweet potato price (vt/kg)			75
12	Fertilizer cost (vt/ha)	26145		Wage rate (vt/day)			1400
13	Herbicide (vt/ha)	5776		Discount rate (%)			8%
14							
15	Year	0	1	2	3	4	
16	Land preparation (vt)	3726	3726	3726	3726		
17	Tuber cuttings (vt)	13649	13649	13649	13649		
18	Fertilizer (vt)		3137	3137	3137	3137	
19	Herbicide (vt)		693	693	693	693	
20	Insecticide (vt)		2047	2047	2047	2047	
21	Transport (vt)		5760	5760	5760	5760	
22	Labour cost (vt)	4032	17640	17640	17640	14112	
23	Revenue (vt)		108000	108000	108000	108000	
24	Net cash flow (vt)	-21407	61347	61347	61347	82250	
25	NPV (vt)	197147					
26	IRR (%)	287%					
27							
28	Annual labour requirement (days)	3	13	13	13	10	

AFM5: canarium (*Canarium indicum*) + plantain (*Musa* spp.) + kava (*Piper methysticum*) + Pacific kauri (*Agathis macrophylla*)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	AG	AP
1	**AFM5 – canarium (*Canarium indicum*) + Pacific kauri (*Agathis macrophylla*) + plantain (*Musa spp.)* + kava (*Piper methysticum*)**															
2																
3	Tree or crop species mixture	Year 1	Year 2-6	Year 7-12	Yr 13-16	Yr 17-31	Yr 32-40	Row spacing (m)	Spacing within rows (m)	Planting density (sph)	Product yield	Yield unit	Product price (vt/kg)	Price unit		
4	Canarium (*Canarium indicum*)	0%	50%	50%	50%	50%	0%	10	9	111	1.0	Factor	50	vt/kg NIS		
5	Plantain (*Musa spp.)*	50%	50%	20%	0%	0%	0%	3	2	1667	1.0	Factor	50	vt/kg		
6	Kava (*Piper methysticum*)	0%	40%	70%	70%	0%	0%	2	2	2500	2400	kg/ha	1800	vt/kg		
7	Pacific kauri (*Agathis macrophylla*)	50%	50%	50%	50%	50%	50%	10	9	111	10	m^3/ha/yr	3000	vt/m^3		
8																
9	**Shared costs**				**Common parameters**				NIS means nuts in shell (but not husk)							
10	Land clearing labour (3 days)	4200			Wage rate (vt/hr)		1400		Kava roots are dried before selling							
11	Sundry tools (vt)	25000			Discount rate (%)		8%		Canarium timber is not included in the sensitivity analysis							
12	Crates and buckets (vt)	10000														
13	Knapsacks (vt)	25000														
14	Land lease fee (vt/ha)	83000														
15																
16	**Annual net cash flows**															
17	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	31	40
18	Shared costs (vt)	-147200														
19	Canarium (vt)		-39456	-4856	-4856	-8094	-3238	-6475	-25345	23264	-27944	142848	202640	262432	433224	
20	Plantain, first rotation (vt)	-41785	337402	323515	317340	312567	304991	293913								
21	Plantain, second rotation (vt)							-16714	134961	129406	126936	125027	121996	117565		
22	Kava ,first rotation (vt)		-259520	-25280	-36480	-36480	-29200	600892								
23	Kava, second rotation (vt)							-454160	-44240	-63840	-63840	-51100	1051560			
24	Kava, third rotation (vt)												-454160	-44240		
25	Pacific kauri (vt)	-5390	-2406	-2406	-2406	-1604	-1604	-1604	-642	-642	-642	-642	-642	-642	-642	600000
26	Overal agroforestry system (vt)	-194375	36020	290973	273598	266389	270949	415851	64734	88188	34510	216133	921395	335115	432582	600000
27	Overall NPV, excl. (vt)	2775365														
28	Overall IRR (%)	86%														

30	**Labour requirement (days) - first 12 years**													
31														
32	Year	0	1	2	3	4	5	6	7	8	9	10	11	12
33	Canarium	4	3	2	6	5	5	6	39	69	98	128	157	187
34	Plantain 1	9	7	7	6	5	5	5						
35	Plantain 2							4	3	3	3	2	2	2
36	Kava 1		12	16	24	24	19	49						
37	Kava 2							21	29	43	43	34	86	
38	Kava 3												21	28.7
39	Kauri	1.4	1.7	1.7	1.7	1.1	1.1	1.1	0.5	0.5	0.5	0.5	0.5	0.5
40	Overall labour requirement (days)	15	24	27	38	35	30	86	71	115	144	164	267	218

	A	B	C	D	E
42	**Sensitivity analysis**		Pessimistic	Expected	Optimistic
43					
44			NPV	NPV	NPV
45	Canarium nut yield (kg/ha)		0.8	1	1.2
46			2533927	2775365	3016803
47	Canarium nut price (vt/kg)		40	50	60
48			2215929	2775365	3334801
49	Plantain yield (kg/ha)		0.8	1.0	1.2
50			2349837	2775365	3200893
51	Plantain price (vt/kg)		40	50	60
52			2273909	2775365	3276822
53	Kava yield (kg/ha)		1600	2000	2400
54			2351606	2563486	2775365
55	Kava price (vt/kg)		1440	1800	2160
56			2513881	2775365	3036849
57	Kauri yield (MAI in m^3/ha)		8	10	12
58			2769841	2775365	2780889
59	Kauri timber price (vt/m^3)		2400	3000	3600
60			2769841	2775365	2780889
61	Wage rate (vt/ha)		1680	1400	1120
62			2415229	2775365	3135501
63	Discount rate (%)		9.60%	8%	6.40%
64			2332978	2775365	3351626

In this agroforestry system, plantain is initially grown as a shade crop, with canarium (for nut production) and kava planted in the second year. Pacific kauri—a slow-growing, low-maintenance and high-value timber species—is also planted immediately. Two six-year rotations of plantain and three four-year rotations of kava are grown, complicating the cash flow and labour requirement sequences. The NPV is about 2.4 million vatu (equivalent to about A$30,000) over the 40 year rotation. The labour requirement (included for up to year 13 then for year 20) increases sharply when canarium nut harvest commences. NPV is most sensitive to plantain yield and price, and also relatively sensitive to the canarium nut price and the wage and discount rate.

	A	B	C	D	E	F	G	H
1	**Financial model for Canarium (*Canarium indicum*)**							
2								
3	**Physical parameters**			Year of maximum yield				12
4	Site and management factor	1		Yield maximum (kg NIS/tree)				100
5	Area planted (ha)	1		Nut yield, yr 7 (kg NIS/tree)				20
6	Distance between rows (m)	10		Nut yield, yr 8 (kg NIS/tree)				36
7	Spacing within rows (m)	9		Nut yield, yr 9 (kg NIS/tree)				52
8	Total number of trees	111		Nut yield, yr 10 (kg NIS/tree)				68
9	Hole digging and planting time (mins/tree)	15		Nut yield, yr 11 (kg NIS/tree)				84
10	Fertilizing or mulching at planting (mins)	2		Nut yield, yr 12 (kg NIS/tree)				100
11	Infilling rate (%)	10%		Timber volume (m^3/tree)				1
12	Infilling time (mins/tree)	3						
13	Weed control, yr 1-3, 3 rounds (mins/tree)	15		**Financial parameters**				
14	Weed control, yr 4-6, 2 rounds (mins/tree)	10		Labour cost (vt/day)				1400
15	Pruning labour, yrs 3 & 5 (mins/tree)	10		Price of seedlings (vt/seedling)				50
16	Fertilizer rate, year 6 on (kg/tree)	1.5		Initial fertilizer or compost cost (vt/tree)				250
17	Labour for fertilizing, yr 6 on (mins/tree)	4		Cost of fertilizer , 13:13:21 (vt/kg)				125
18	Plantn. maintenance, yr 7 on (mins/tree)	5		Nut price (vt/kg NIS)				50
19	Nut collection labour (mins/kg)	4		Nut transport cost (vt/kg)				6
20	Nut processing labour (mins/kg)	4		Timber price (vt/m^3)				2000
21	Year of first crop	7		Discount rate (%)				8%
22	Yield of first crop (kg NIS/tree)	20						

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	AE	AF
24	**Cash flow table and performance criteria**															
25	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	29	30
26	Capital outlays															
27	Cost of seedlings (vt)	5550														
28	Planting and fertilizing (vt)	5504														
29	Initial fertilizer cost (vt)	27750														
30	Infilling cost (vt)	652														
31	Total capital outlays (vt)	39456														
32																
33	Annual operating costs															
34	Weed control cost (vt)		4856	4856	4856	3238	3238	3238								
35	Pruning labour (vt)				3238		3238									
36	Fertilizer cost (13:13:21) (vt)							20813	20813	20813	20813	20813	20813	20813	20813	20813
37	Fertilizer application labour (vt)							1295	1295	1295	1295	1295	1295	1295	1295	1295
38	Plantn. supervision & maint. labour (vt)								1619	1619	1619	1619	1619	1619	1619	1619
39	Nut collection labour (vt)								25900	46620	67340	88060	108780	129500	129500	129500
40	Nut post-harvest processing labour (vt)								25900	46620	67340	88060	108780	129500	129500	129500
41	Transport of nuts (vt)								12210	21978	31746	41514	51282	61050	61050	61050
42	Total operating costs (vt)		4856	4856	8094	3238	6475	25345	87736	138944	190152	241360	292568	343776	343776	343776
43																
44	Annual revenue															
45	Total nut yield (ton NIS)								2220	3996	5772	7548	9324	11100	11100	11100
46	Timber revenue (vt)															222000
47	Revenue from nut sales (vt)								111000	111000	333000	444000	555000	555000	555000	777000
48																
49	Net cash flow (vt)	-39456	-4856	-4856	-8094	-3238	-6475	-25345	23264	-27944	142848	202640	262432	211224	211224	433224
50	Net present value (vt)	1091105														
51	Internal rate of return (%)	34%														
52	Annual labour requirement (days)	4	3	2	6	5	5	6	39	69	98	128	157	187		

	A	B	C	D	E	F	G	H
1	**Financial model for plantain**							
2								
3	Area planted (ha)	0.5		Labour req excl harvest, yr 5 (days/ha)				10.5
4	Site and management factor	1.0		Labour req excl harvest, yr 6 (days/ha)				10.5
5	Row spacing (m)	3		Harvest labour, yr 1 (days/ha)				15
6	Spacing within rows (m)	2		Harvest labour, yr 2 (days/ha)				15
7	Number planted	833		Harvest labour, yr 3 (days/ha)				12.5
8	Land preparation cost (F$/ha)	17516		Harvest labour, yr 4 (days/ha)				10
9	Sucker cost (vt/sucker)	8.5		Harvest labour, yr 5 (days/ha)				7.5
10	Mixed fertilizer cost, year 1 (vt/ha)	26655		Harvest labour, yr 6 (days/ha)				7.5
11	Mixed fertilizer cost, yr 2-6 (vt/ha)	39982		Plantain yield, yr 1 (kg/ha)				18326
12	Annual herbicide cost (vt/ha)	5776		Plantain yield, yr 2 (kg/ha)				18000
13	Annual fungiciide cost (vt/ha)	15676		Plantain yield, yr 3 (kg/ha)				17500
14	Annual insecticide cost (vt/ha)	9312		Plantain yield, yr 4 (kg/ha)				17000
15	Transport cost (vt/kg)	5.69		Plantain yield, yr 5 (kg/ha)				16500
16	Labour reqt, excl harvest, yr 0 (days/ha	18.5		Plantain yield, yr 6 (kg/ha)				16000
17	Labour reqt, excl harvest, yr 1 (days/ha	13.5		Fruit price (vt/kg)				50
18	Labour reqt excl harvest, yr 2 (days/ha)	13.5		Wage rate (vt)				1400
19	Labour reqt excl harvest, yr 3 (days/ha)	12.5		Discount rate (%)				8%
20	Labour reqt excl harvest, yr 4 (days/ha)	10.5						
21								
22	Year	0	1	2	3	4	5	6
23	Land preparation cost (vt)	8758						
24	Cost of plantain suckers (vt)	7109						
25	Fertilizer cost (vt)		13327	19991	19991	19991	19991	19991
26	Herbicide cost (vt)		2888	2888	2888	2888	2888	2888
27	Fungicide cost (vt)		7838	7838	7838	7838	7838	7838
28	Insecticide cost (vt)		4656	4656	4656	4656	4656	4656
29	Transport cost (vt)		52110	51183	49761	48340	46918	45496
30	Labour requirement, days	18.5	28.5	28.5	25	20.5	18	18
31	Labour cost (vt)	25900	39900	39900	35000	28700	25200	25200
32	Production (kg/ha)		9163	9000	8750	8500	8250	8000
33	Sales revenue (vt)		458150	450000	437500	425000	412500	400000
34	Net cash flow (vt)	-41785	337402	323515	317340	312567	304991	293913
35	NPV (vt)	1422433						
36								
37	Annual labour requirement (days)	9	7	7	6	5	5	5

	A	B	C	D	E	F	G
1	**Kava financial model**						
2							
3	Area planted (ha)	0.4		Labour requirement, year 2 (days/ha			61
4	Site and management factor	1		Labour requirement, year 3 (days/ha			61
5	Distance between rows (m)	2		Labour requirement, year 4 (days/ha			48
6	Spacing within rows (m)	2		Labour reqt, yr 5, excl harvest (days/l			48
7	Number of plants	2500		Harvest labour reqt, year 5 (days/ha)			75
8	Land preparation cost (vt/ha)	6800		Yield (kg/ha)			2400
9	Number of cuttings per mound	4		Kava production (kg)			960
10	Cutting cost (vt/unit)	60		Transport cost, year 5 (vt/kg)			20
11	Planting materials cost (vt/ha)	600000		Transport cost, year 5 (vt/ha)			47771
12	Herbicide cost (vt/ha)	5800		Kava price (vt/kg)			1800
13	Labour requirement, year 0 (days/ha	30		Wage rate (vt/day)			1400
14	Labour requirement, year 1 (days/ha	41		Discount rate (%)			8%
15							
16	Year	0	1	2	3	4	5
17	Land preparation and planting (vt)	242720					
18	Herbicide cost (vt)		2320	2320	2320	2320	2320
19	Transport cost (vt)						19108
20	Labour cost (vt)	16800	22960	34160	34160	26880	68880
21	Revenue from kava sales (vt)						691200
22	Net cash flow (vt)	-259520	-25280	-36480	-36480	-29200	600892
23	NPV (vt)	44332					
24							
25	Annual labour requirement (days)	12	16	24	24	19	49

	A	B	C	D	E	F	G	H	I	J	K	L	AO	AP
1	**Financial model for Pacific kauri (*Agathis macrophylla*)**													
2														
3	**Physical parameters**			Mean annual increment (m^3/ha/year)					10					
4	Area planted (ha)	0.5		Harvest age (years)					40					
5	Site and management factor	1.0		Harvest volume (m^3)					200					
6	Distance between rows (m)	10		Timber volume per tree (m^3)					2					
7	Spacing within rows (m)	9		Harvest age (yrs)					40					
8	Total number of trees	55												
9	Hole digging time (mins/tree)	10		**Financial parameters**										
10	Fertilizing and planting time (mins/tree)	2		Price of seedlings (vt/seedling)					50					
11	Fertiliizer rate at planting (gms/tree)	100		Initial fertilizer or compost cost (vt/tree)					130					
12	Weed control labour, yrs 1-3 (mins/tree)	15		Timber selling price (vt/m^3)					3000					
13	Weed control labour, yrs 4-6 (mins/tree)	10		Wage rate (vt/day					1400					
14	Plantation management, yr 7 on (min/tree)	4		Discount rate (%)					8%					
15														
16														
17	Year	0	1	2	3	4	5	6	7	8	9	10	39	40
18	Capital outlays													
19	Cost of seedlings (vt)	2750												
20	Planting and fertilizing labour (vt)	1925												
21	Fertilizer at planting (vt)	715												
22	Total capital outlays (vt)	5390												
23														
24	Annual operating costs													
25	Weed control (vt)		2406	2406	2406	1604	1604	1604						
26	Other plantation management (vt)								642	642	642	642	642	
27	Total operating costs (vt)		2406	2406	2406	1604	1604	1604	642	642	642	642	642	
28														
29	Harvest revenue (vt)													600000
30														
31	Net cash flow ($)	-5390	-2406	-2406	-2406	-1604	-1604	-1604	-642	-642	-642	-642	-642	600000
32	Net present value ($)	8090												
33	Annual labour requirement (days)	1.4	1.7	1.7	1.7	1.1	1.1	1.1	0.5	0.5	0.5	0.5	0.5	0.5

10. Assistance measures for smallholder forestry and agroforestry, with particular reference to Fiji and Vanuatu

Steve Harrison and Robert Harrison

Abstract

A wide variety of approaches have been adopted to support forestry and agroforestry, to ensure future timber supply, household livelihoods and environmental benefits of vegetation in the landscape. This working paper reviews the measures to promote forestry and agroforestry at the national, regional and individual smallholder level in various countries, but with particular emphasis on those trialled, proposed or potentially suitable for Fiji and Vanuatu. In general, measures include command-and-control instruments (most often concerned with environmental protection), market-based instruments (various subsidies and grants, e.g. free seedlings, assistance with planting, payments for early weed control), moral suasion, provision of information (e.g. field days on how to establish a nursery and produce seedlings, plant trees or wildlings, carry out pruning and thinning, and generally to progress to best management practice), plantation joint venture or shared equity schemes, more supportive land-use policy, governance and planning schemes (including removal of impediments to planting and selling produce), and introduction of national and regional greening programs with substantial funding support. Some innovative approaches for funding large-scale programs to support forestry and agroforestry are identified. Research and development to support the provision of information can be a critical input. In general, a mix of instruments is likely to be the most effective approach. On the basis of this evidence, policy implications are drawn for promotion of forestry and agroforestry in Fiji and Vanuatu.

INTRODUCTION

Much has been written about agroforestry in Pacific island countries, including in Fiji and Vanuatu, notable contributions being the books of Thaman and Clarke (1993), Elevitch and Wilkinson (2000a), Alavalapati and Mercer (2004) and Kumar and Nair (2006). In general, the theme has been of the benefits of agroforestry, and the concern over decline in agroforestry, with 'agrodeforestation' taking place in recent decades, including in Fiji and Vanuatu. This has been attributed in part to "official emphasis on and encouragement of commercial monocropping, commercial production of livestock, and industrial forestry" (Thaman and Ali 1993), and also urbanisation of the population (CoA 2011). This raises the question of whether agroforestry, with the various notable benefits it provides, can be promoted and expanded.

Governments typically support forestry to ensure a timber supply in the future and to generate environmental benefits, while recognising the long payback period for forestry investments and hence reluctance of companies and landholders to engage in this enterprise. Back in 2000, Elevitch and Wilkinson (2000b) listed 'additional benefits of trees' (services as distinct from products) in Pacific island countries as aesthetics, legacy, cultural values, watershed, habitat, erosion control and soil improvement. Watershed would be recognised to include flood mitigation, this being an important issue for tourism in Pacific island countries. In recent years, major attention has been given to the carbon sequestration benefits of forestry, which would now certainly be added to the list.

Agroforestry development faces many of the same problems as forestry. In this context, Bartlett et al. (2012, p. 399) drew attention to the obstacles for sustainable forest management in 'small island nations':

> The difficulties associated with sustainable forest management are compounded in small island states, where there are several challenges including barriers to market mechanisms, lack of infrastructure, logistical challenges of moving logs and timber between islands or overseas, and in some cases, severe weather (e.g. cyclones). These small nations may also have relatively small Forestry Departments with few resources to support the development of sustainable forest industries. Frequently, transaction costs in small island states are higher than in comparable continental nations, particularly with regard to trade. Typically, capital costs are higher, transport is slow and expensive, and economies of scale are harder to achieve.

In a broader context, small island nations face major challenges in achieving economic growth and development. ACIAR (2015, p. 22) summed up succinctly the difficulties faced by measures aimed at improving broad-based economic growth and enhancing private-sector development in Pacific island countries.

> Key challenges in achieving these measures include the islands' physical isolation, human and organisational capacity constraints, land tenure disputes and uncertainties, lack of infrastructure, poor transportation logistics, poorly developed supply chains, lack of harmonisation between countries (e.g. in biosecurity laws), and the need to link with major international markets. In addition, erosion of tariff preferences, population and urban growth, migration of skilled labour, resource depletion and degradation, risks from climate change, high and fluctuating food and energy prices, and political and economic constraints to effective policy implementation are also recognised as significant impediments to development and progress.

Given the small populations, low government revenues and other challenges faced by Pacific island nations, there is an obvious need for some external funding assistance, and prioritisation of measures in domestic land-use policy.

This working paper examines the broad range of measures which can be adopted to promote smallholder agroforestry in Pacific island countries, and their relevance for Fiji and Vanuatu. The emphasis is on non-industrial and mixed-species plantings by individual smallholders and by communities.

STRATEGIES FOR PROMOTING AGROFORESTATION

There is a long history of providing support for individuals to plant trees, notably in Europe. For example, in the United Kingdom financial assistance was provided by the Forestry Grant Scheme, then the Woodland Grant Scheme (commencing in 1988). As noted by Wikipedia (2016), "In the 1990s, a programme of afforestation resulted in the establishment of Community Forests and the National Forest, which celebrated the planting of its seven millionth tree in 2006."[1]

The European Forest Institute produced a major report evaluating the financing of forestry in various European countries (EFI 2004). Appendix 5 of the EFI report classified forestry assistance measures as in Box 1. More applied summaries of the incentives and disincentives under various government policy documents for vegetable agroforestry in the Philippines and Vietnam are provided by Catacutan et al. (2008).

The literature on environmental policy instruments provides similar approaches to promoting forestry and agroforestry, from the viewpoint of gaining environmental benefits. Some measures to encourage environmentally desirable actions include market-based instruments, command-and-control measures, information provision, moral suasion and infrastructure support.

Market-based methods for forestry and agroforestry activities include subsidies, grants, free inputs (seedlings and other propagules, fertiliser) and payments for environmental services (PES) or watershed services (PWS). Assistance with nursery development, and with producing or gaining access to planting materials (seed, cuttings, grafted material, root suckers) as well as obtaining superior germplasm (from identified superior mother trees, seed orchards and hedgerows, or tissue culture laboratories) is also sometimes provided.

1 While earlier schemes focused on timber production—initially mainly conifers but later broadleaf species—more recent programs including the Community Forests and National Forest initiatives included a high proportion of conservation plantings.

Command-and-control methods consist of government regulations to enforce or prevent particular actions, the most notable being bans on tree clearing. Command-and-control measures are probably not relevant to bringing about agroforestry planting in Fiji or Vanuatu, although land-clearing restrictions are in place to prevent deforestation.

Information provision can include research and development (R&D) on new technology, and extension and training activities. A useful form of extension is through provision of demonstration sites, often established for research purposes, where people interested in planting timber or multi-species agroforestry can view and discuss well-managed stands, which are permanently open to the public or have open days. Various such sites are accessible in Fiji and Vanuatu.

Moral suasion often takes the form of an advertising program to appeal to people's sense of what is desirable behaviour, e.g. public announcements that people should establish more agroforestry because it is 'good for the environment'. Infrastructure support—e.g. improved roads, setting up market areas, assistance in sawmill development—can be critical for improving product market and value chains.

Survey findings in a series of ACIAR forestry projects in the Philippines carried out by the University of Queensland Tropical Forests Group over the last 15 years revealed that many forestry training events (particularly on nursery operations and seed and wildling collection) had been provided, but training was mostly for short periods (up to a week) and a one-off activity, and hence had low effectiveness. Further, farmers often expressed the view that they had had sufficient training, but they needed more practical support to commence planting activities.

Provision of free seedlings and financial assistance for planting have relatively low cost and have been used widely to motivate tree planting. These can be expected to be taken up by some landholders, but usually do not lead to widespread planting activity. Without further assistance, after the first year or two the landholders frequently lose interest and do not provide the necessary plantation maintenance. This appears to be the case in major tree planting programs, and applies to some extent in developed as well as less developed countries.

In many cases the government is not only a facilitator but also a major obstacle to forestry and agroforestry development, imposing regulations (and costs) on tree planting and registration of planted trees, and restrictions over harvesting and transport of plantation timber. In these situations one method of facilitating tree planting is to remove 'red tape', i.e. to introduce more supportive governance.

In low-income developing countries, and notably in Asia and the Pacific, foreign technical and financial assistance is often sought for the various forestry and agroforestry support measures listed above.

Box 1. Forestry assistance measures, classified by the European Forest Institute (EFI 2004).

Financial assistance

Direct financial assistance (appearing in the accounts of targeted beneficiaries)

– Grants (direct, unrequited payments; input-oriented or output-related quid pro quo contracts)

Indirect financial assistance (third-party involvement by offering cheap loans)

– Soft loans
– Loan guarantees

Tax-related subsidies

Tax concessions
Tax exemptions

Technical assistance

Extension services (advisory services, training courses)
Forest management planning

Assistance in kind

Supply of infrastructure, machinery, plantings etc.

Compensations

Compensation payments based on the contractual agreements

REGIONAL AND NATIONAL REFORESTATION PROGRAMS

Major regional and national forestry programs have been undertaken to bring about large-scale forestry and agroforestry projects. If major agroforestry development were being contemplated in Fiji or Vanuatu, some insights could be gained from reviewing experiences in such programs. Notable models of long-term community afforestation programs in developing countries are the Joint Forest Management (JFM) program in India, the Community-Based Forest Management (CBFM) and Community-Based Resource Management (CBRM) programs in the Philippines, and the Community Forest User Groups (CFUG) program in Nepal.[2] These programs have typically involved some management and harvesting of existing native forests as well as large-scale tree planting. In each program, some form of community organisation is assisted to manage the forestry or agroforestry establishment and maintenance. In the Philippines CBFM program, community organisers have been employed to assist in the establishment of people's organisations which manage the programs under government rules. Notably, in the CBFM, agreements may involve communal planting, support for a number of individual property rights plantings, or a combination of these.[3]

Probably the most effective of the above programs is the Nepal CFUG, although this is to some extent a handover of the management of existing forestry and benefits from government to communities. Romero (2013) reported that there were approximately 18,000 CFUGs in Nepal, with about 5 million members involved in protecting about 1.3 million hectares of forestry (26% of the country's forest area). The movement was formalised in 1993. The membership includes ethnic and caste groups, and both women and men.[4]

CBFM in the Philippines seems to have relied on substantial loan finance, and had moderate success. Some obstacles to harvesting trees have arisen because of government equity in the plantings and dissatisfaction with timber prices offered, and from periodic logging bans after environmental disasters attributed to deforestation, including floods and landslides. Emtage and Suh (2005) provided a concise summary of the strengths, weaknesses, opportunities and threats of the CBFM.

While CBFM and CBRM plantings were mostly monoculture plantations, an alternative model known as rainforestation farming (RF), with more of an agroforestry focus, was championed by Leyte State University. This system, in which both native and exotic timber species are planted, as well as fruit trees, is described by Magraf and Milan (2004). Some participants in the RF program have harvested fast-growing exotic timber species, making greater space available for the slower growing but high-value indigenous tree species.

2 The Philippines CBFM and CBRM programs and some other community forestry initiatives are described in Harrison et al. (2004b), and various papers on the Nepalese CFUGs are included in recent issues of the journal Small-scale Forestry.

3 An example of a regional planting program in a developed country—the Community Rainforest Reforestation Program (CRRP) in north Queensland, Australia, described by Vize et al. (2005)—provides another model for promoting landholder tree planting, with particular focus on rainforest cabinet timber species not traditionally grown commercially but of high conservation value. The CRRP was a joint program between the national and Queensland state governments, and a number of local governments in the Queensland wet tropics, as well as an employment and training scheme for young people, conducted in the early 1990s. Government funding was provided for mixed-species plantings and early maintenance on private land. While the initial plan was to plant about 30,000 ha of forestry over 30 years, the area planted and duration of the program fell far short of this aspiration. Some of the woodlots were well managed, others neglected, but the program raised considerable interest in growing rainforest trees and a substantial area of private planting outside the program subsequently took place (Harrison et al. 2004a).

4 According to Romero (2013), "CFUGs have legal personality, earn and manage funds generated from forest use, and devise their own operational plans. They develop and enforce their own constitutions in a participatory manner, overseeing governance mechanisms that ensure transparency and accountability such as financial audits, well-being ranking, public hearings and submission of annual reports to the district forest office. They monitor the condition of the forest and biodiversity as well as their own group's governance mechanisms and compliance with local rules, and develop their own indicators to monitor social and environmental development."

Other major reforestation efforts have involved fixed-term programs. One of the most ambitious was Project 661 or the Five Million Hectares Project in Vietnam. Other examples of major tree planting programs, described in Wikipedia, include Indonesia's attempt in 2007 to plant nearly 80 million trees in a single day, the Philippines National Greening Program designed to plant 1.5 billion trees over six years (2011–2016), and the Billion Trees Campaign launched in 2006 by the United Nations Environment Programme (UNEP), under which China is reported to have planted 2.8 billion trees and India 2.1 billion trees, with substantial areas also planted in Ethiopia, Mexico and Turkey. After more than 12 billion trees had been planted by December 2011, UNEP formally handed management of the program over to the not-for-profit Plant-for-the-Planet Foundation, based in Munich, Germany.

In general, forestry and agroforestry projects in developing countries have been supported by grant and loan funding, including from the World Bank, Asian Development Bank, European Union, the German international cooperation agency GIZ, international NGOs, domestic governments, company sponsorship and private philanthropists. Funding opportunities also arise from selling carbon credits, although anxieties have arisen in Fiji and Vanuatu about the complex approval procedure for clean development mechanism projects and risks when dealing with 'carbon cowboys' (unscrupulous carbon credit dealers seeking to quickly acquire the sequestration rights to forests from rural landowners) (Anon. 2010).

PROPOSALS TO PROMOTE TIMBER INDUSTRY DEVELOPMENT OR EXPANSION WITH A PARTICULAR TREE SPECIES

Frequently, proposals are made for the large-scale planting of a particular tree species for which a strong market is available. Harrison et al. (2007) carried out a detailed assessment of the prospects of expanded planting of hoop pine (*Araucaria cunninghamii*) on the southern Atherton Tableland in tropical north Queensland, Australia. Local governments had become alarmed at the fall in milk prices and potential contraction in the local dairy industry, and sought an alternative land use. Hoop pine was favoured as a native tree species, which has been grown for many years in government plantations (now privatised) and as street trees on the tableland. The Australian government, through the Department of Transport and Regional Services, made funding available for a comprehensive evaluation of 'hoop pine expansion'. The evaluation comprised an assessment of financial, social and environmental impacts of planting. A forestry joint venture scheme between the state government and landholders was proposed, to finance the venture. A partial recovery of dairying together with large increases in land values on the tableland led to the loss of political momentum for more forestry, and no major planting program eventuated.

An interesting partnership investment package was developed by the Forest Products Commission (FPC) in Western Australia to promote development of a sandalwood industry. As reported by FPC (2007), "The FPC offers commercial partnerships with farmers to grow sandalwood in the Wheatbelt and some other areas of the State with a minimum average annual rainfall of approximately 400 mm. … The FPC advises farmers where to plant the trees, carries out the planting, manages the plantation and harvests it when mature. A financial package provides landowners with a choice of up-front payments, annuities, profit sharing, or a combination of these."

Page et al. (2012) proposed an expansion in the growing of sandalwood (*Santalum* spp.) in Vanuatu. Sandalwood has been an important export for Vanuatu, but native stocks have declined. Heartwood in the trunk and roots of sandalwood is highly valuable for carving, while powdered sandalwood can be used to make incense sticks, and extracted oils are used in perfumes, soaps, cosmetics and therapeutics. Edible nuts are also produced. Page et al. (2012) described joint venture plantings as a means of sourcing capital. They noted (p. 53) that "The investors entering into these joint ventures in Vanuatu range from wage earners in the urban centres to foreign investors", and that "Joint ventures may involve the investor providing tools (chainsaw, fencing, spades, knives, etc.), seedlings and/or poly planter bags, as well as money to employ local labour to assist with clearing, planting and maintenance. The landowner provides the land and agrees to manage and maintain the trees for the entire rotation."

Various authors in the 2012 Vol.14, No. 4 issue of the International Forestry Review, and Virannamanga et al. (2015), examined the potential for a plantation-based whitewood (*Endospermum medullosum*) industry in Vanuatu. Whitewood has been recognised as a valuable indigenous timber species in Vanuatu, and is currently found in relatively small quantities in the wild and in agroforestry plantings. There is potentially high overseas demand for the timber, including in Japan where light-coloured timber is popular. Whitewood could be grown in areas where older coconut plantations are not being replanted due to decline in copra export price and yield. A proposal has been developed by Virannamanga et al. (2015) for a program for promotion of whitewood production, processing and export.

Various joint venture forestry programs have been implemented in Australia, typically promoting a single species or a small number of species, including hardwood species for which there has been limited commercial plantation experience. The joint venture partners have mainly been landholders combining with governments or private companies. An example is the joint venture scheme in south-east Queensland, in which Gympie messmate (*Eucalyptus cloeziana*) was planted in approximately 10 ha woodlots. Equity was shared between landholders and the state government. The state government subsequently sold a 99-year plantation lease on its forestry resources to Hancock Queensland (HQ Plantations Pty Ltd). More recently, many of these joint venture agreements have been dissolved, through confidential agreements.

These examples illustrate the potential for expansion in planting of a high-value timber species, particularly through joint venture schemes, but they have also revealed various challenges which arise in bringing about forestry development and in equity-sharing programs. Landholders in general lack enthusiasm for forestry joint ventures, where they to some extent lose control over forestry on their own land. Timber companies are also cautious of joint ventures, because of the relatively high management time required for dealing with landholders. A common problem in promoting non-traditional timber species is lack of a sufficiently large and regular supply to support a cost-effective processing chain, especially in small island economies.

MEASURES TO INCREASE THE GENETIC QUALITY OF MATERIALS PLANTED

Various measures can be adopted to increase the genetic quality of agroforestry planting material. Extension and training can be provided to encourage smallholders who produce their own seedlings or collect wildlings to be selective in their choice of planting materials. A relatively low-cost method for improving the genetic quality of seedlings for smallholder timber production is the establishment of seed orchards and hedgerows, and identification and utilisation of superior mother trees. Governments can also establish seed supply chains, as has been achieved in Indonesia (e.g. see Roshetko et al. 2008; Mercado et al. 2010).

Thailand and Vietnam have developed programs in which tissue culture laboratories produce large quantities of planting materials of high genetic quality for distribution to landholders (Harrison and Gregorio 2010). In Thailand the focus is on teak (*Tectoris grandis*), and landholders can collect an annual quota of propagules. In Vietnam, propagules are produced of several acacia and eucalypt species, particularly for log timber and pulpwood for paper production. These programs involve substantial staffing, technical expertise and cost, i.e. they involve relatively high costs for both establishment and annual operation.

PITFALLS IN PROVISION OF TREE-PLANTING SUPPORT

Forestry and agroforestry assistance is widely provided by governments, but does not always produce favourable results. Perhaps the simplest of forestry and agroforestry support measures is the provision of free seedlings, which can be expected to encourage planting activity. However, recipients may plant on unsuitable sites, or in shallow holes and without any fertiliser or organic matter, or without any initial watering when there is little soil moisture. Stand management in the first few years is critical to plantation success. Often there is poor weed control, and sometimes failure to exclude grazing animals, or theft of seedlings. A further downside when seedlings are provided gratis by government is that the private seedling nursery industry will be discouraged. Where landholders are given funding to carry out the tree planting—even on their own land—there have sometimes been stories of them burning the planted area to obtain further income from tree replanting.

Support for seedling nursery development is also a common form of assistance for forestry and agroforestry, but it is often not recognised that this requires considerable skill. Seedlings in nurseries may develop defective root systems (J rooting or coiled roots, especially when pots are placed on concrete) or be damaged on outplanting (taproot severed, or sunburned if not properly sun-hardened). Poor root formation can result in trees which are not windfirm, especially on wet sites, and hence high losses in cyclones and typhoons.

While training events are frequently provided to promote on-farm seedling production and tree planting, these are usually short and one-off events, and have low effectiveness. Major forestry support programs often have the advantage of social preparation, guidance by a community organiser who may facilitate development of a people's organisation, as well as technical advice from the implementing government agency. But even this support can have weaknesses: a study in the Philippines by Astoria (2004) found that community organiser support for two years was often insufficient to develop a stable people's organisation with responsible financial management.

In Vietnam, where many tissue culture laboratories have been developed, there have apparently been quite a few financial failures among these. Tissue culture laboratories typically focus on one or a small number of tree species, and are more suitable for relatively large monoculture forestry plantations, and where there is sustained demand for planting materials, e.g. to support pulpmills.

Government policies can have negative impacts on forest and agroforestry. For example, measures to discourage illegal logging, such as the tree registration program of the Philippines which imposes a time and monetary cost on smallholders, and fear of prosecution for not following complex rules, would appear to sometimes discourage tree planting.

Some of these problems can be overcome by project design, e.g. spreading financial assistance over a sufficiently long period to cover the main weed control period, and making continued technical support available.[5]

IMPLICATIONS OF SUPPORT MEASURES ELSEWHERE FOR EXPANSION OF AGROFORESTRY IN FIJI AND VANUATU

To what extent do forestry support arrangements from elsewhere fit the Fiji and Vanuatu situation? Some initial comments can be made from an assessment of the particular circumstances of forestry and agroforestry in Fiji and Vanuatu. The situation in these countries has the following characteristics.

- Mostly individual rather than community plantings practised (compared with CBFM, JFM and CFUG programs).
- Many small-area plantings by individual households—often less than 1 ha—as in household gardens and periurban agroforestry plantings.
- A focus on Pacific island priority native species, though also on priority domesticated and naturalised species. [6]
- High concern for environmental benefits due to forest loss in recent years, hence the need to include species with high environmental contributions.
- Frequent occurrence of severe storms (cyclones).
- Relatively secure land tenure for indigenous landholders (though community rather than

5 A collection of research papers on seedling production and plantation development issues is provided in Harrison et al. (2008).

6 According to Nichols and Vanclay (2012), "Domestication of new species involves the entire value chain from identification of candidate species, through production and management, to uptake by communities and markets." Wikipedia states that "In biology, naturalization is any process by which a non-native organism spreads into the wild and its reproduction is sufficient to maintain its population. Such populations are said to be naturalized."

individual titling), and less secure tenure for long-term land uses for non-indigenous people.

- Relatively weak supply chains for farm products, including timber, fruits and vegetables.
- Low incomes and wealth, hence a need for an early cash flow from agroforestry plantings.
- Small domestic populations hence low domestic timber demand.
- Abundant land resources for agroforestry, including on land previously used for sugarcane plantations, or carrying aged coconut plantations where replanting is not planned, though many sites are degraded and challenging for agroforestry establishment.

In some respects these are similar problems to those faced in Asian countries, although Pacific island countries face even greater constraints due to their low populations typically spread over many islands, and high vulnerability to global warming and extreme weather. Further, promotion of agroforestry—as distinct from monoculture forestry—typically involves the requirement for planting material for a number of tree species, which has cost and logistical implications.

THE UNITED NATIONS FORUM ON FORESTS STUDIES INTO FACILITATING FINANCING FOR SUSTAINABLE FOREST MANAGEMENT IN SMALL ISLAND DEVELOPING STATES AND LOW FOREST COVER COUNTRIES

A series of case studies was commissioned by the United Nations Forum on Forests (UNFF) examining measures for facilitating financing for sustainable forest management in developing countries, with Sue (2010) preparing the report for Fiji. Information was collected through a survey and a workshop, and input was obtained from government and non-government forest and cross-cutting sectors representing finance, environment, indigenous peoples and intergovernmental/bilateral aid agencies.

The Fiji case study produced 13 recommendations on "strategies for increasing financing flows for SFM" or sustainable forest management. Recommendations included: formulating a national forest development strategy; strengthening collaboration between Pacific agencies and NGOs in forest conservation and accessing grants; encouraging the private sector and corporate entities to exhibit corporate social and environmental responsibility with a tax rebate; establishing incentives for forest establishment; encouraging public–private partnerships to fund large-scale public infrastructure developments, such as the management of forested watersheds; encouraging the development of non-timber and non-wood forest products linked with assistance provided towards small and medium enterprises; introducing a green fee for foreign visitors and a levy on timber sales; promoting agroforestry- and forest-based tourism; and implementing a REDD+ policy. While these recommendations are rather general, they go a long way towards developing a policy framework for promoting forestry and agroforestry in the country.

In a workshop report by UNFF (2012, p. 8), Tuisese of Conservation International was reported as presenting in relation to forestry finance that "Types of financing in Fiji include: annual budget allocation, taxes or levy, income generating activities, enhancement of existing use of trust funds, carbon offsets, biodiversity offsets and debt for nature swaps."

DETERMINING THE LEVEL OF FINANCIAL SUPPORT NEEDED TO PROMOTE SMALLHOLDER FORESTRY AND AGROFORESTRY PLANTING

In terms of the assistance needed to promote the adoption of agroforestry, knowledge of the costs of switching to this form of land use and cost implications of major assistance programs as described above can be drawn upon. The former may be investigated by identification of appropriate agroforestry systems, and financial evaluation of the private costs to landholders of these systems, with particular attention to startup costs. As noted by Mercer and Alavalapati (2004, p. 304), "if private profitability is not sufficient to encourage adoption of agroforestry systems that produce large amounts of public goods, analyses like these are required to determine whether government incentives are appropriate and if so the size and composition of incentives required to encourage socially efficient rates of agroforestry adoption."

The financial ability of landholders to establish agroforestry plantings would depend on their financial reserves and ability to borrow funds, and on the amount of expenditure required to establish these plantings. The latter could be determined by examining the cumulative cash flows or 'project balances' estimated by financial analysis of agroforestry projects. Designing agroforestry systems which have early generation of cash inflows—for example by including cash or food crops—would help to minimise negative project balances during the agroforestry startup period. At the same time, an assessment of attitudes to agroforestry adoption would be required. This could take the form of a survey of households, together with discussions with key informants (e.g. community leaders, local government officers, extension officers).

The costs of introducing government programs to promote agroforestry will vary greatly depending on the approach adopted, e.g. program spatial scope, intensity, and level of technology. More information is needed to make specific recommendations about the most appropriate support measures. Programs can be designed to assist small-scale growers, or major community or industrial planting programs can be supported, the emphasis in this paper being on the former.

In designing support measures for agroforestry in Fiji and Vanuatu, it is of course necessary to understand the recent and current projects undertaken in these countries with domestic funding and foreign aid support, and their achievements. Appendix A provides some observations on forestry and agroforestry support measures already introduced in Fiji and Vanuatu. Appendix B reviews the role of ACIAR and other international agencies in supporting forestry and agroforestry.

DISCUSSION

Many forestry and agroforestry support programs have been implemented in many countries, including in developing countries, and some lessons can be observed from the approaches to promoting forestry and agroforestry, and successes and failures. Forestry and agroforestry generally require considerable expenditure and high labour inputs, and can face relatively high risk (including from storm and wildfire damage). 'Encouragement' programs—such as free seedlings, short-term training events, some individual technical advice, and moral suasion—will likely promote some planting. However, more major support programs are generally required to generate the momentum for large-scale planting. Fiji and Vanuatu have already undertaken various forestry and agroforestry initiatives. As indicated in Appendix A, these initiatives have involved some highly technical approaches, and have been supported by a number of international agencies. However, it seems reasonable to conclude that more international support and planning is required for major agroforestry recovery and expansion.

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APPENDIX A. SOME FORESTRY AND AGROFORESTRY SUPPORT MEASURES IN FIJI AND VANUATU

Governments in Fiji and Vanuatu have introduced various measures to promote forestry and agroforestry, sometimes with international finance support. Some examples found on the web are briefly summarised below, with relevant URLs. These examples illustrate the following:

- There is a desire to promote agroforestry for multiple goals, including human nutrition and income security, and environmental benefits of species conservation.
- There is a strong emphasis on training in relation to production of planting materials.
- Various demonstration sites have been established to promote mixed-species agroforestry in both countries.
- There is an emphasis on designing agroforestry systems for different locations in the landscape (the 'ridge to reef' concept).
- There is concern over climate change, lowland flooding, tidal surges and sea-level rise.
- There is political interest in agroforestry development, and the desire for cooperation between countries within the Pacific region.
- Various international sources of funding have been accessed for promotion of agroforestry.
- There is some advanced technology (including the Centre for Pacific Crops and Trees and the tissue culture laboratory at the Pacific Community (SPC) in Fiji) to support the conservation, production and distribution of agroforestry planting materials.
- Both Fiji and Vanuatu have well-established banking systems and some microfinance institutions, but bank finance for agroforestry is probably difficult and expensive to obtain.
- No really large national tree planting programs have yet been undertaken in either country, and major agroforestation programs would require external funding.
- Recent severe cyclones (Pam in Vanuatu in 2015 and Winston in Fiji in 2016) have caused major forestry damage and necessitated international aid for recovery programs.

1. The Regional Germplasm Centre (RGC) was established in Fiji in 1998, and in 2007 was renamed the Centre for Pacific Crops and Trees (CePaCT). "The aim of CePaCT is to assist Pacific Island countries and territories (PICTs) to conserve the region's genetic resources, and to provide access to the diversity they need … with priority given to the region's staple crops: taro, yam, sweet potato, banana, cassava and breadfruit. … This diversity needs to be conserved, evaluated and made available to countries so that farmers can use this resource to improve food production and income generation. The centre not only conserves the region's valuable genetic diversity, but also undertakes the important mission of distributing it … The Centre also has a strong research programme …".

   <http://lrd.spc.int/the-centre-for-pacific-crops-and-trees-cepact>

2. Mamanuca Environment Society (MES) noted in 2010 the decision of the Ministry of Fisheries and Forests in Fiji to launch an initiative to plant one million trees. A number of tourist resorts—through community and school programs—supported this initiative. It was later reported that 1.4 million trees had been planted under this program, although the most frequently planted 'tree' or species was the coconut palm.

   <http://mesfiji.org/a-million-trees-for-the-future>

3. A statement was made by Fiji Prime Minister J.V. Bainimarama in 2011 that "The establishment of tax free zones, duty concessions and areas that were once restricted to local businesses only is now accessible to foreign investors."

   <http://fijiconsulategeneral.org.au/wp-content/uploads/2013/06/FIJI-AGRICULTURE-INVESTMENT-GUIDE1.pdf>

4. A four-day regional training workshop on 'Tree propagation for agroforestry in the Pacific' was held by SPC at the Forestry Training Centre in Suva in 2012 and attended by delegates from 14 Pacific island countries. The training included "practical sessions on plant propagation and other nursery practices, such as species selection, seed collection, seed treatment and germination, potting and maintenance of

seedlings, and vegetative propagation techniques." Financial support was provided by the Japanese International Cooperation Agency (JICA) and the European Union through the Forest Research Network of the Pacific.

<http://www.spc.int/en/presentation/861-spc-encourages-agroforestry-as-an-integrated-farming-approach.html>

<http://www.cifor.org/forenet/publications/pdf_files/SPC_Agroforestry_Training_Workshop%20_Report.pdf>

5. SPC conducted a two-day on-farm agroforestry training course on the farm of Charles McCay in Tabia in northern Fiji in 2013, for representatives from the departments of agriculture and forestry, NGOs and farmers/tree growers. Training was provided on grafting and marcotting techniques. Agroforestry trials had been developed on the farm for flat and sloping land. "Indigenous tree species such as Dakua (*Agathis macrophylla)* and Vesi (*Intsia bijuga)* were planted on top of the slope, while trees of economic value, such as sandalwood were planted together with citrus and other fruit trees in the middle of the slope with root crops over the base of the slopes. Similarly, on flat land, crops such as taro, pigeon pea, okra, cowpea, water melon, eggplant and capsicum were planted. Sweet potato and bananas produced by tissue culture at SPC's Centre for Pacific Crops and Trees (CePACT) were also planted." The training was cofunded by United Nations Development Program's (UNDP) Global Environment Fund under its small grant project.

<http://www.spc.int/en/about-spc/1513-spc-conducts-agroforestry-training-in-northern-fiji.html>

6. A visit was made in 2014 by Fiji's Minister for Primary Industries and Provincial Development Inia Seruiratu to Tabia, Labasa, Vanua Levu to an on-farm agroforestry demonstration site on the farm of Charles McCay supported by SPC under a memorandum of understanding. "The goal of this project is to develop a fully integrated farming system that provides food, nutrition and income security and, at the same time, protects the soil from erosion and degradation and contributes to the conservation of indigenous tree species." SPC provided Charles McCay with construction materials, fencing materials, planting tools, seeds and seedlings to establish his nursery. Indigenous tree species (sandalwood, vesi and dakua) and tissue-cultured sweetpotatoes and bananas have been planted. A cocoa plantation has been established, intercropped with turmeric to "control weeds and provide extra income to the farmer while the cocoa is growing". Funding is provided by the European Union, USAID and UNDP.

<http://www.spc.int/fr/library/1620-agroforestry-demo-site-excites-fijis-minister-for-primary-industries.html>

7. A tissue culture facility was commissioned in Fiji in 2014, by the Minister for Agriculture, Fisheries and Forests, Rural and Maritime Development and National Disaster Management, Mr Inia Seruiratu. "The laboratory will provide supplies of tissue culture plants to established nurseries around the country where they will be kept in readiness for communities affected by disasters ... the Ministry of Agriculture can continue to produce clean disease-free planting material as required to sustain increased production level. ... SPC works in partnership with Pacific countries and territories, CGIAR (Consortium of International Agricultural Research Institutes) and the Global Crop Diversity Trust to source and acquire new crop diversity for the region. … SPC also works closely with the Biosecurity Authority of Fiji to fast-track the release of suitable new crop varieties to Fiji farmers … The new laboratory will also be used to support … floriculture, horticulture and forestry."

<http://www.spc.int/fr/spcnews/1599-fijis-new-tissue-culture-facility-commissioned-.html>

8. Two large reforestation projects currently operating in Fiji are the Nakauvadra community-based reforestation project of Conservation

International, located in the far north of Viti Levu in Ra Province, and the 'Reforestation for the degrading foothills of the sugar belt' (RFDF) project (now called the Reforest Fiji Project), which commenced in 2014 and is based in Lautoka and funded by the EU. Both are briefly described in Working Paper 5 of this publication, 'Opportunities and constraints to agroforestry expansion on underutilised land in western Viti Levu, Fiji'.

9. The Forest Conservation Unit of the Vanuatu Department of Forests developed "draft conservation strategies for four top priority Vanuatu tree species, sandalwood (*Santalum austrocaledonicum*), whitewood (*Endospermum medullosum*), Pacific kauri (*Agathis macrophylla*) and Santo kauri (*Agathis silbae*)." Development of these strategies "has involved input from the entire Department, and been assisted by the AusAID-funded SPRIG (South Pacific Regional Initiative on Forest Genetic Resources) … An essential step in this process has been consultation with key stakeholders, including village communities, industry and NGOs."

   <http://www.fao.org/docrep/008/x4133e/x4133e15.htm>

10. The Vanuatu Department of Forests reported in 2010 that the 'Enhancing rural livelihood development through establishment of community forestry nurseries' project had commenced in Vanuatu "with the objectives to advance reforestation (woodlot and plantation establishment) into rural communities through establishment of forestry nurseries; and also improve the knowledge of communities on tree planting through training and information." It was envisaged that 360,000 seedlings would be produced over three years. Twelve seedling nurseries were established throughout Vanuatu, with funding assistance from the New Zealand International Aid and Development Agency.[7]

11. SPC carried out an agroforestry training workshop with participants from the Department of Forestry, Agriculture and Livestock at the Vanuatu Agricultural Research and Technical Centre (VARTC) in Luganville, Espirito Santo in 2014. The workshop had a focus of "enhancing the knowledge and skills of the participants in the areas of nursery design and management, seeds and seedling production, and plant propagation." This was part of the initiative on 'Enhanced climate change resilience of food production systems in Pacific Island countries and territories', which is funded by USAID.

    <http://www.spc.int/en/events/1714-spc-runs-agroforestry-training-in-vanuatu.html>

12. According to SPBD Microfinance Ltd (Fiji) in 2014, "Five foreign commercial banks (ANZ, Westpac, Colonial, Bank South Pacific, and Bank of Baroda) and three credit companies are active in Fiji. Microfinance providers (for both credit and savings) include three microfinance institutions, four village banks and a cooperative program."

    <http://www.spbdmicrofinance.com/spbd-network/fiji>

13. According to P.B. McGuire, in year 2000 there were four commercial banks in Vanuatu. "Three are branches or subsidiaries of foreign banks—ANZ Banking Group and Westpac Banking Corporation of Australia and Banque d'Hawaii …The fourth is the government-owned National Bank of Vanuatu (NBV)." It was also noted that the private commercial banks have little outreach among low-income households, and that "The NBV was established in 1989 with the objective to provide commercial banking

7 A number of URLs recorded for this section of the working paper, including for this source, have become unavailable since cyclone Pam struck Vanuatu.

services to the indigenous ni-Vanuatu people [and] has much greater outreach in rural areas." McGuire further noted that "the only significant microfinance program in Vanuatu is the Vanuatu Women's Development Scheme (VANWODS), a replication of the Grameen Bank that is financed by UNDP and implemented through the Department of Women's Affairs."

<http://www.microfinancegateway.org/sites/default/files/mfg-en-paper-microfinance-in-vanuatu-institutions-and-policy-jun-2000.pdf>

14. A memorandum of understanding between Fiji and China was recently signed (2015) which "will enable both countries to share experiences on forestry developments, training, research, climate change and the exportation of forest products to China". This could result in major assistance for forestry projects in Fiji, although specific arrangements are not yet clear.

    <http://www.fiji.gov.fj/Media-Center/Press-Releases/FIJI-AND-CHINA-SIGN-MOU-ON-FORESTRY-COOPERATION.aspx>

15. Vulnerability to extreme weather events has been dramatically evident by recent tropical cyclones in Vanuatu (cyclone Pam, March 2015) and Fiji (cyclone Winston, February 2016). Notably, prompt efforts have been made to restore forestry after these events, with international support. After an assessment of forest damage by the Department of Agriculture and Rural Development (DARD) in Vanuatu, the recommendation was made to establish a total of 20 nurseries with the capacity to produce a total of 50,000 seedlings annually. Further, "demonstration plots of Agro-forestry will be established at each nursery site for farmers and annual field days for farmers to inspect the plantings".

    <http://pacificpolicy.org/2015/05/restoring-forestry-and-fisheries-after-cyclone-pam/>

    An appeal is being made to raise funds for nursery repairs and other activities, with support from the Institute of Foresters of Australia and Foresters Without Borders.

    <http://www.forestry.org.au/news/collecting-money-for-vanuatu-forests-after-cyclone-pam>

    According to SPC, "The Pacific Community (SPC) and the European Union (EU), through their joint initiative, Reforest Fiji, are making available more than 250,000 tree seedlings to help affected Fijian communities recover from tropical cyclone Winston."

    <http://www.spc.int/en/media-releases/2404-reforest-fiji-seedlings-contribute-to-cyclone-winston-recovery.html>

APPENDIX B. ACIAR CONTRIBUTIONS TO FORESTRY AND AGROFORESTRY R&D ACTIVITIES IN PACIFIC ISLAND COUNTRIES

Lowy Institute research reported by Safi (2015) indicates that Australia, the USA, Japan and New Zealand in that order are the major contributors to development finance in Pacific island countries, but there has been a rapid increase in aid from China (which does not publish official figures about its aid programs), particularly to Papua New Guinea, Fiji, Samoa and Vanuatu. This section briefly examines the role of ACIAR in supporting forestry and agroforestry, with particular emphasis on the Pacific region.

ACIAR is Australia's specialist agricultural research for development agency. It works to improve partner countries' trade and economic growth through mobilising cutting-edge research. ACIAR was established under an Act of Parliament in 1982 as a statutory authority to operate as part of the Australian Aid Program, "to encourage research for the purpose of identifying, or finding solutions to, agricultural problems of developing countries" (http://aciar.gov.au/aboutus). ACIAR program areas include: fisheries; forestry; agribusiness; soil management and crop nutrition; horticulture; animal health; agricultural development policy; and livestock production. Activities are carried out in the Pacific; East Asia; South and West Asia; and Eastern and Southern Africa. Funding is provided for both bilateral (one partner country) and multilateral programs.

ACIAR's principal goals are "to reduce food insecurity, improve livelihoods, and care for the natural resource base for agriculture. ... It plans, funds and manages R&D projects that are carried out by Australian public sector groups (including universities, state departments and other research providers such as CSIRO), NGOs and private sector groups, in partnership with their counterparts in developing countries" (http://aciar.gov.au/files/node/2632/13-09-07%20Project%20Development%20Guidelines.pdf). International partners implementing ACIAR projects with developing-country research institutions include CGIAR centres and non-government organisations.

ACIAR's role in the Pacific

ACIAR supports R&D projects in the Pacific island countries of Fiji, Kiribati, PNG, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu. Recent annual budgets for this region have been A$14.61 million actual expenditure for 2013–2014, A$6.64 million budget allocation for 2014–2015, and $6.03 million planned budget for 2015–2016 (http://aciar.gov.au/publication/aop2015-16).

Specific activities supporting forestry and agroforestry in these projects involve biological and economic research, including field trials (of timber, fruit and nut trees and food crops), wood technology trials, marketing and supply chain studies, landholder surveys, training workshops, conferences presenting project findings, and production of scientific and extension materials. Interaction between ACIAR and in-country team members facilitates information exchange. There is typically a significant training component within projects, and separate training events are supported.

Some recent ACIAR forestry and agroforestry research projects in Pacific island countries

The following list of recent ACIAR projects in the Pacific islands with a forestry or agroforestry component has been compiled from information provided by A. Bartlett (Forestry Research Program Manager) and web sources, including the ACIAR Annual Operational Plans (AOPs). Information on the projects can be found at the web addresses listed in the AOPs.

As apparent from this table, ACIAR has funded research on a wide variety of topics, particularly in PNG and Vanuatu. Research topics have included germplasm improvement, small plantation and agroforestry management regimes, wood processing, and processing and marketing of non-timber forest products. There has been some focus on domestication of traditional Pacific island tree species—notably special-purpose timber (including whitewood and sandalwood) and nut species (including *Canarium* and *Terminalia* species). The research has provided a strong background for developing effective agroforestry systems for Pacific island countries.

Some areas where further research support appears promising include community forestry, identification of timber and intercrop species suited to difficult sites—such as those with relatively low winter rainfall and degraded planting sites or prone to cyclone damage—and in general forestry and agroforestry policy. These in turn could be supported by research on governance, financial and non-market values, and carbon sequestration benefits, to facilitate a cost–benefit perspective for land-use policy.

Project number or publication code	Project title	Country	Status
FST/2014/067	Enhancing value-added products and environmental benefits from agroforestry systems in the Pacific	PNG, Vanuatu, Fiji and Solomon Islands	Commenced 2015
FST/2012/042	Enhancing management and processing systems for value-adding in plantation-grown whitewood in Vanuatu	Vanuatu	Completed 2016
FST/2010/013	Developing markets and products for the Papua New Guinea Canarium nut industry	PNG	Completed 2016
FST/2009/062	Development of advanced veneer and other products from coconut wood to enhance livelihoods in South Pacific communities	Samoa, Solomon Islands	Current
FST/2015/020	Assessing genetic diversity of natural and hybrid populations of *Santalum yasi* in Fiji and Tonga	Fiji and Tonga	Report released 2016
ADP/2014/013	Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu	Fiji and Vanuatu	Completed 2015
ADP/2014/012	Improving livelihoods and economic progress through rehabilitation of degraded catchments in Fiji and Vanuatu	Fiji and Vanuatu	Completed 2016
FST/2005/050	The potential of incorporating high-value tree species in Papua New Guinea agroforestry systems to enhance landowner livelihoods	PNG	Final report FR2014-06 released 2014
FST/2004/050	Value-adding to Papua New Guinea agroforestry systems	PNG	Final report FR2014-10 released 2014
FST/2005/089	Improved silvicultural management of *Endospermum medullosum* (whitewood) for enhanced plantation forestry outcomes in Vanuatu	Vanuatu	Final report FR2013-07 released 2013
FST/2012/010	Growth and wood properties of *Terminalia catappa* from agroforestry systems in Vanuatu	Vanuatu	Final report FR2013-31 released 2013
FST/2007/020	Improving silvicultural and economic outcomes for community timber plantations in Solomon Islands by interplanting with *Flueggea flexuosa* and other Pacific agroforestry species	Solomon Islands	Final report FR2013-09 released 2013
FST/2004/009	Facilitating the availability and use of improved germplasm for forestry and agroforestry in Papua New Guinea	PNG	Final report FR2013-17 released 2013
FST/2004/055	Domestication and commercialisation of *Canarium indicum* in Papua New Guinea	PNG	Final report FR2012 released 2012
mn151 (ACIAR Monograph No. 151)	Vanuatu sandalwood: growers' guide for sandalwood production in Vanuatu	Vanuatu	Published 2012
tr079 (ACIAR Technical Report 79)	Opportunities for the smallholder sandalwood industry in Vanuatu	Vanuatu	Published 2012
CoP024	The International Forestry Review, Vol.14(4), 2012, an issue on domesticating native tree species for development in small island nations, particularly whitewood (*Endospermum medullosum*) in Vanuatu	Mostly Vanuatu	Published 2013

11. Prospects for agroforestry in Vanuatu: findings from a survey

Steve Harrison and Lazarus Aising

Abstract

As part of ACIAR project ADP/2014/013, 'Promoting sustainable agriculture and agroforestry to replace unproductive land-use in Fiji and Vanuatu', a small survey was conducted to explore smallholders' attitudes to agroforestry in the villages of Epau and Etas on Efate Island in Vanuatu. Land areas of farmers were found to be small (not more than about 5 ha), and the lack of farming equipment was notable. Various food crops were grown, including citrus, vegetables and notably 'sea cabbage', and were sold locally and in Port Vila. Some integration of timber trees and food crops was noted, although no particular mixtures could be identified as favoured. Strong interest was found in growing whitewood and sandalwood, which are relatively short-rotation species with high-value timber. Major constraints to expansion of mixed-species agroforestry included lack of land, lack of finance, and concern about availability of markets for farm-grown produce. The lack of more than very basic tools and equipment, which would make tree planting and maintenance difficult, would also be a limitation. It would appear that even a small amount of assistance would encourage greater agroforestry adoption. Assistance measures identified as encouraging increased agroforestry included provision of finance, improved market access, access to more farming land, and funding for purchase of hand tools and other equipment (e.g. chainsaws), and fencing. Mention was also made of extension and provision of planting materials.

INTRODUCTION

Agroforestry has been a traditional practice in the Pacific islands for centuries (Elevitch and Wilkinson 2000), and a number of important benefits have been identified from multi-species agroforestry (MSA) systems, including home gardens (Thaman et al. 2006). During the colonial era of the 19th and early 20th centuries, there was a decline in agroforestry with increased attention to large-scale plantations and export industries. Since the 1970s, there has been a research focus on MSA systems.

Forestry is a relatively small industry in Vanuatu. According to ITTO (2010), "No formal PFE [private forest enterprise] has been created in Vanuatu because all forests are under customary ownership. The role of the national government in forest management is in policy development, planning, protection, silvicultural principles and guidelines, and the supervision of logging companies." According to Index Mundi (2015), the main agricultural products of Vanuatu are copra, coconuts, cocoa, coffee, taro, yams, fruits, vegetables, beef and fish. Production of coconuts as well as cattle raising have been important industries, and intercropping of coconut palms as well as silvopastoral systems combine well with these industries.

A small landholder survey was conducted with the objective of obtaining information about attitudes to agroforestry, MSA practices and constraints, and measures which could be taken to promote agroforestry, on Efate in Vanuatu.

THE STUDY SITES

Data were collected from households in Epau village and Etas village of Shefa Province on Efate Island, Vanuatu.[1] Epau is on the east coast of Efate, about 37 km from the capital Port Vila, while Etas is on the south coast about 9 km from Port Vila. Both

1 Shefa Province is one of the six provinces of Vanuatu, and includes Efate, Epi and the Shepherd Islands.

have populations of less than 1,000 persons. Epau has more than 1,000 ha of land, with many farmers (who are native to the area) having about 5 ha of land; Etas has less than 50 ha of land, with many migrants from other islands living in the area and seeking employment in Port Vila.[2]

According to the Vanuatu Meteorological Services (2007), the Vanuatu climate has two seasons, the cold (or dry) season from May to October and the hot (wet or cyclone) season from November to April. Further, "During the wet season, rainfall is particularly high on the windward side (southeast parts) of the bigger islands and scarce during the dry season especially on the leeward sides (northwest part). … Rainfall on the island of Efate shows this particular pattern. On the windward side, annual rainfall is measured from 2400 mm–3000 mm and is almost half that amount on the leeward side." The two villages are located in high-rainfall areas of Efate.

The natural vegetation was tropical rainforest, and the soils are moderately fertile. Both villages suffered considerable damage from tropical cyclone Pam in March 2015, shortly after the survey was undertaken.

RESEARCH METHOD

A short questionnaire was developed and interviews carried out with selected smallholders engaged in agroforestry (though not necessarily intercropping) in the two villages in March 2015. Questions were included on current resources and land-use activities, including any agroforestry practice, and on future intentions in relation to agroforestry. Respondents were also asked about what incentives they would require to adopt or expand their agroforestry systems. Although the samples were small (five in Epau village and four in Etas village) and were not randomly selected, some interesting information was obtained. The research method could perhaps be best described as a number of case studies: five in Epau village, and one with four participants in Etas village. The 'survey' was supported by collection of other information about the villages, including about climate, soils and farming practices.

2 In this area, farmers have purchased land on a 75-year lease, and built houses. If they haven't paid off their properties, they pay monthly instalments. Most farmers in Etas pay off their land through instalments over 3 to 5 years.

RESULTS

The five properties visited in Epau village were all on customary land and had on average area of 4.8 ha. All respondents mentioned growing timber, notably whitewood, mahogany and sandalwood (Table 1). Nut and fruit species were also grown, including Polynesian chestnut or namambe, navel or cutnut (Figure 1), and fruit trees (especially citrus). The four properties visited in Etas were all 0.125 ha homestays. All mentioned growing sandalwood and citrus, and three mentioned growing namambe.

Various fruit and vegetable crops were mentioned in the villages, including banana, island cabbage (five mentions; Figure 1), root crops (taro, yam, cassava), orange, mandarin, capsicum, avocado, papaw, ginger and sugarcane (two mentions) (Table 2).

Farm resources and activities

When asked "What capital items do you have on the farm? (buildings, vehicles, plant and equipment)", respondents identified bush knives (40–50 cm in length, used for weeding and other farming activities), axes and other hand tools (including spades and other digging tools). It would appear that respondents in general lacked vehicles, motorised machinery or draft animals, and used hand tools for farming activities.

On-farm and off-farm employment

The labour force per farm averaged 5.0 people (an average of 2.1 adults and 2.9 youths). Members of five families had off-farm work, including all four Etas respondents (with two members working off-farm in four cases and one in the other). None of the respondents employed other people to work on their land.

Product marketing

All respondents appeared to sell produce both locally and in Port Vila. The main products sold include island cabbage, banana, citrus, root crops, cucumber, onion, watermelon, tomato and corn.

Table 1. Timber and fruit tree species reported on survey farms.

Scientific name	Common names
Barringtonia edulis	Cutnut, navel[a]
Dracontomelon vitiense	Nakatambol[a]
Endospermum medullosum	Whitewood
Flueggea flexuosa	Poumuli, namamau[a]
Inocarpus fagifer	Tahitian or Polynesian chestnut, namambe[a]
Pometia pinnata	Taun, island lychee, nandao[a]
Santalum austrocaledonicum, S. yasi, S. album	Sandalwood
Syzygium clusiifolia, syn. *Eugenia clusiifolia*	Bush cherry, lilly-pilly, nakafica[a]
Terminalia catappa	Natapoa[a]

[a] Bislama name.

Table 2. Other species most commonly mentioned as grown on survey farms.

Scientific name	Common name
Manihot esculenta	Cassava
Abelmoschus manihot	Island cabbage
Piper methysticum	Kava
Colocasia esculenta	Taro
Dioscorea spp., incl. *Dioscorea alata*	Yam

Figure 1. Two popular species grown in the villages: Island cabbage (*Abelmoschus manihot*; left) and cutnut (*Barringtonia edulis*; right). Photos: Richard Markham, ACIAR

Current agroforestry practices

All respondents indicated they grow timber trees, most reported they grow fruit or nut trees, and all reported they grow food crops, although the extent of intercropping was unclear.

Perceived constraints to agroforestry

Lack of finance and concern about unavailability of timber markets were viewed as the main constraints to agroforestry for landholders in Epau village, though lack of money, labour and knowledge as well as profitability concerns were also mentioned. Lack of land, finance, markets and knowledge were considered the major constraints to agroforestry in Etas village, but low profitability, high investment risk and shortage of labour were also of concern.

Other constraints identified in one or both villages included lack of materials, machinery and vehicles for transport; pest and disease risk; farmer's age; and long wait for returns. Presumably the last of these problems could be overcome if annual or short-rotation crops were intercropped with timber, fruit or nut trees.

Attitudes to agroforestry assistance measures

Respondents were asked what type of assistance they would require to expand agroforestry, or adopt agroforestry (if not currently engaged in this practice). All but one respondent answered that they would expand or adopt agroforestry if support measures were available, the one commenting that he was too old. A wide assortment of assistance needs was identified, including finance (four respondents), market access (four, all from Epau village), hand tools (four), land access (three, all from Etas village, one mentioning resolution of land disputes), equipment (two, one of whom mentioned a chainsaw), and fencing.

Labour hiring

Six said they would be prepared to hire labour if they increased their agroforestry, while two others said they would do most of the work themselves, and one stated explicitly that he would not hire labour.

Use of agrochemicals

Only two said they would use fertiliser, all in Epau village replying no to this question. Attitudes towards use of pesticides were more divided, four stating they would use these, four stating they would only use traditional methods, and one stating they would use both chemicals and traditional methods for pest and disease control.

DISCUSSION AND CONCLUSIONS

As only a small number of farmers were interviewed, the research objectives were only partially achieved, but some interesting findings were obtained. There was notable interest in growing the tree species whitewood and sandalwood, which are relatively short rotation species and can be logged in about 20 years. Growing food crops—including 'sea cabbage'—was also a high priority. While all respondents appeared to practice agroforestry in the sense of growing timber trees, most growing fruit or nut trees, and all growing food crops, the questions failed to identify the extent of intercropping.

The lack of more than very basic tools and equipment, which would make tree planting and maintenance difficult, was evident. All respondents appeared to rely on sale of crops as a revenue source, and availability of markets was a major concern. There was little interest in using fertiliser on crops, though use of pesticides had greater acceptance.

Respondents were clearly resource poor, in terms of land and finance. It would appear that even a small amount of assistance would encourage greater MSA planting. Lack of finance was a major problem. Other assistance which would be useful would be extension, planting materials, and hand tools.

SUGGESTIONS FOR FURTHER RESEARCH

This study would lend itself to a more expanded research activity. A larger sample with greater spatial coverage on Efate would provide further insights to support the research objectives outlined in this paper.

Some expansion to the questionnaire would be useful, including more specific questions on current farming practices, what plant and equipment farmers have (providing a specific list of items) and their attitudes to particular types of agroforestry systems. A comparison could be made between smallholders who had adopted agroforestry in the form of intercropping, and those who had not. Information could be sought on silvopastoral systems. Collection of some financial data would allow greater reliability in financial evaluation of mixed-species agroforestry systems.

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APPENDIX A. THE SURVEY QUESTIONNAIRE

APPENDIX A. THE SURVEY QUESTIONNAIRE

Questionnaire on Prospects for Agroforestry

Farm code: ________________ Questionnaire number: _________

Name of Respondent: ____

Address: ____

Interviewer: ____________________________ Date of Interview: ____________________

Good morning/afternoon (Name of Respondent)

I am (Name of interviewer) from the ACIAR research projects on Promoting Sustainable Agriculture and Agroforestry in Fiji and Vanuatu, Leyte. We are conducting a survey to gather some information about your farming resources and systems and attitude towards agroforestry.

I assure you that your identity and individual responses will be kept confidential.

Thank you.

Ask each question and fill in each answer

Add: DK = for 'don't know' ; RA = for 'refuse to answer' ; and NA = for 'not applicable'.

Farm resources and activities

1. What area of land do you farm? ha
2. What is your land tenure?
3. How is your land used?

Landuse activity (particular crop, timber or fruit tree species, pasture)	Area (ha)

Notes:

4. What if any agroforestry (mixed trees and other species, or grazing systems) do you have?

5. How many family members work on the land?

Number of adults? Number of youths?

6. How many family members have any employment off the farm, and in what types of jobs?

Number of adults	Type of employment	Number of youths	Type of employment

7. Do you employ any non-family people to work on the farm? If yes, please provide details (number of people, number of hours, pay rate).

8. What capital items do you have on the farm? (buildings, vehicles, plant and equipment)

9. What farm-produced produce do you sell, and where do you sell it?

I would now like to ask you about agroforestry.

10. What agroforestry systems do you have on your land, if any? (species mixture, area)

11. What harvesting have you done on this agroforestry?

12. Do you intend to establish any (more) agroforestry?

If yes, please provide details (species or mixtures, area, purpose).

13. If no AF planning intentions, would you like to plant (more) forestry or agroforestry?

If so, what species or mixtures would you like to plant?

Also, what prevents you from planting (more) agroforestry?

15. Which of the following would constrain you from planting (more) agroforestry?

Constraint	Severity as a constraint (high, medium, low)
Lack of land	
Lack of money	
Land not suitable	
Insufficient labour time	
Not likely to be sufficiently profitable	
Lack of markets	
Fire risk too high	
Lack of knowledge about how to manage agroforestry	
Pest or disease risk too high	
Too long a wait for financial returns	
Other constraints: Please list	

16. If government assistance were available, would this make you interested in planting (more) agroforestry?

17. What type of assistance and how much of this assistance would you need to establish (more) agroforestry?

18. If you were to establish (more) agroforestry, would you hire labour to do so, or do the planting yourself?

Would you use any fertiliser?

Would you use any pest or disease control measures, and if so which ones?

12. Policy and legal framework for promoting sustainable agroforestry in Fiji

Md Saiful Karim, Alexander Button-Sloan, Samuela Lagataki, Sairusi Bulai, Tevita Kete and Mohammad Alauddin

Abstract

This paper critically examines the key legal and policy issues in developing sustainable agroforestry on unproductive land in Viti Levu, Fiji. Much of this land has become unproductive because of the decline in Fiji's sugar industry, on which the country has long relied. Interest in other land uses has thus arisen. Recent reports indicate that only a very minimal amount of agroforestry is being practised in Fiji, and it is pertinent to examine the opportunities and constraints facing the promotion of sustainable agroforestry development. This paper presents an overview of existing laws and policies in Fiji relevant to agroforestry and provides some policy recommendations for promotion of agroforestry. It appears that, although there is strong support for agroforestry in agricultural and forestry polices, practical efforts and the coordination for implementation of the broader policy objectives are lacking.

INTRODUCTION

Fiji does not have a separate law or policy or strategy for agroforestry. However, laws and policies relating to land-use systems and tenure, agriculture, land degradation, forestry, biodiversity and biosecurity are directly or indirectly relevant to agroforestry. Some other policies, including those dealing with export of produce and climate change, are also relevant for agroforestry. All relevant laws and policies are described below, and listed in Table 1.

LAWS AND POLICES FOR LAND SYSTEMS AND TENURE

According to the Fiji Government's 2007 National Action Plan to Combat Desertification/Land Degradation and to Mitigate Against Drought, "A total of 13,140 leases will expire between 1997 and 2028. The exodus of people from the agricultural sector will not only have an adverse effect on this sector but also poses other social and economic problems for the government. There is

Table 1. Fijian laws discussed in this paper.

Agricultural Landlord and Tenant Act (Cap 270)	Environment Management Act 2005
Agriculture Marketing Authority Act 2004	Forest Decree 1992
Coconut Industry Development Authority Act 1998	iTaukei Land Trust Act 1940
Constitution of the Republic of Fiji 2013	Land Use Decree 2010
Crimes Decree 2009	National Trust of Fiji Act (Cap. 265)
Criminal Code Act 1899 (Qld)	Native Land Trust (Amendment) Decree 201
Decree No. 44 of 2009	Native Land Trust (Leases and Licenses) Regulations, 1984

already evidence of urban squatter problems. If the government does not find a solution to this effect, additional social and economic problems will burden the nation. This will have a drastic effect on the already problematic infrastructure in Fiji's towns and cities and the creation of more new squatter settlements" (UNCCD National Focal Point 2007).

Most of the land suitable for agroforestry development in Fiji is held customarily, i.e. it is *iTaukei* land. In accordance with the custom and tradition of the iTaukei people, this land is held communally by tribal groups, known as *mataqali*. It is the mataqali as a collective clan or tribe, not each of the individuals within that collective, which appears on the title of registration. Importantly, iTaukei lands are inalienable; they cannot be sold, transferred, mortgaged or otherwise encumbered, except to the Crown. This is explicitly recognised in section 28 of the Constitution of the Republic of Fiji 2013.

Prior to July 2010, administration and management of leases relating to customary land was governed exclusively by the iTaukei Land Trust Act 1940 (iLTA). From July 2010 leasing of iTaukei land is also governed by the new regime established under the Land Use Decree 2010 (the Decree). This regime effectively 'competes' with the iLTA regime, in the sense that land developers may opt for either regime.

Enacted in 1940, the iLTA was the then colonial administration's response to growing demand for sugarcane, rice and other cropping land uses by Indo-Fijians. The purpose of the iLTA was to facilitate commercial leasing of iTaukei land, while ensuring sufficient land was reserved for the use, maintenance and support of current and future indigenous Fijians (iTaukei Land Trust Act 1940, s 9).

For the effective implementation of iLTA's leasing process, the iTaukei Land Trust Board (iLTB) was established as a statutory body tasked with negotiating and managing the leasing of iTaukei land on behalf of, and for the benefit of, customary owners. Removal of communal landowners' control was considered necessary because of landowner reticence to enter into leases (Dodd 2012). To overcome this, the iLTB effectively subsumed the powers and control which communal owners exercised over their lands prior to the enactment of iLTA, although legal ownership is not relinquished by the mataqali (Waisake Ratu No 2 case 1991[1]). Ultimately, any purported dealing with iTaukei land is null and void if it lacks the consent of the iLTB, which must also be satisfied that the land is not being used by the landowners and will not be required for their use, maintenance or support. While the iLTB is not legally required to obtain the consent of the mataqali (Waisake Ratu No 2 case 1991), in practice the mataqali exercise significant control over the part of their land which is leased, and the iLTB implements a policy of consulting with them (Native Title Trust Board case 2010[2]). It is noteworthy, however, that there have been instances in which the iLTB disregarded this policy and leased customary land without the consent of the iTaukei (Fiji Times 2010). In respect of land designated as a native reserve, however, a lease can only be entered into between mataqali, and only after the iLTB obtains their consent (iTaukei Land Trust Act 1940, s 16(2)).

It has been suggested that the iLTA suffers from many critical shortcomings, notably its failure to achieve its purpose of appropriately balancing inalienability of iTaukei land with economic sustenance (Dodd 2012). The Rural Land Use Policy (RLUP) explicitly highlighted the challenges in the existing regime as constraining land use development in Fiji (Ministry of Agriculture, Sugar and Land Resettlement 2006). The Agricultural Landlord and Tenant Act governs leasing of land for substantially agricultural purposes (discussed below). As mentioned above, since 2010 regulation of leasing of iTaukei land is now also governed by the parallel regime established under the Land Use Decree 2010. The land reforms effected by the Decree reflect the aims of improving land utilisation and increasing agricultural production envisaged in the Roadmap for Democracy and Sustainable Socio-Economic Development 2010–2014 (the Roadmap) (Ministry of National Planning 2009).

The Decree established the 'land use bank' as the register for leases issued under the Decree, while the newly established 'land use unit' system replaces the

1 Waisake Ratu No 2 case. 1991. Waisake Ratu No 2 v Native Land Development Corporation & Native Title Land Trust Broad [1987] FJSC 9; [1991] 37 FLR 146, 161 (Cullinan J).

2 Native Title Trust Board case. 2010. Native Title Trust Board v Subramani [2010] FJCA 9 at [8], [10].

mataqali model and provides the basis for valuation, issuance and renewal of leases, and rent collection (Land Use Decree 2010, s 8). While these leases may be for terms of up to 99 years (Land Use Decree 2010, s 10), ownership of the land stays with the mataqali, whose consent is still required to legally transfer a customary estate (iTaukei Land Trust Act 1940, s 5(2)).

Notably, the Decree relinquishes the iLTB's powers and control with respect to leasing administration. Unlike under the iTaukei Land Trust Act 1940 regime, however, there is greater direct representation of mataqali on the iTaukei Land Trust Board, with five of the eleven members being mataqali (Native Land Trust (Amendment) Decree 2010, s 2). The Prime Minister alone has sole discretion to designate iTaukei land for leasing, and this applies regardless of any conflict with the provisions of the iLTA (Land Use Decree 2010, s 9(1)). Neither the exercise of this discretion, nor the terms and conditions of approved leases, may be challenged before any adjudicative body (Land Use Decree 2010, s 15(1)). This discretion is also not subject to any duty to consult with, or obtain the consent of, the mataqali of the lease. Moreover, the mataqali of the designated land is prevented from exercising any legal rights to use or occupy the land once designated (Land Use Decree 2010, s 4) with the land remaining designated indefinitely. However, use of this new leasing regime is uncommon and most of the agricultural leasing is currently done under the iLTB regime.

LAWS AND POLICES RELEVANT TO AGRICULTURE

Fiji's legal framework for agriculture-related activities comprises 33 pieces of legislation. Some of these are discussed below.[3]

Dealings of agricultural land—namely leases and licences—are governed by the Agricultural Landlord and Tenant Act (ALTA). According to a Fiji Government report, "[t]he land tenure system and lease issued under the native and crown land through the Agriculture Landlord's Tenants Act is not conducive to the sustainable land resources management, where the leases tend to mine the land for economic gains, knowing very well that the lease will expire after 30 years of occupation. [It is] [t]herefore resulting in high degree of land degradation" (UNCCD National Focal Point 2007). In other words, the insecurity of land tenure may discourage farmers from introducing sustainable agricultural practices like agroforestry as these may need long-term investment.

Longer duration leases are technically possible for agroforestry, as forestry leases. The ALTA defines agricultural land as "land, together with any buildings thereon, used or proposed to be used predominantly for the growing of crops, dairy farming, fruit farming, forestry, horticulture, bee keeping, poultry keeping or breeding or the breeding, rearing or keeping of livestock" (Agricultural Landlord and Tenant Act, s 2). This definition may create some conflict because it includes forestry and horticulture leases within the ambit of agricultural leases. Therefore, the lease period for these purposes will be 30 years only. This may create a problem regarding the financial viability of agroforestry. According to Fiji Forestry Department officials "[n]ative leased lands are, however, almost always problematic, with long-term forestry leases often challenged by customary landowners. Land tenure is, therefore, often considered to be an impediment to industrial plantation development and commercial development" (Leslie and Tuinivanua 2010).

3 Those not be discussed but relevant for agriculture are the following: Animals (Contagious Diseases) Act (Cap. 160); Animals (Control of Experiment) Act (Cap. 161); Animal Importation Act (Cap. 159); Banana Export and Marketing Act (Cap. 155); Birds and Game Protection Act (Cap. 170); Brands Act (Cap. 163); Cooperative Dairy Companies Act (Cap. 119); Copra Industry Loans Act (Cap. 153); Crop Liens Act (Cap. 226); Dairies Act (Cap. 118); Dogs Act (Cap. 168); Drainage Act (Cap. 143); Fencing Act (Cap. 167); Fruit Export and Marketing Act (Cap. 154); Ginger Council of Fiji Act 1996; Goat (Ear marks) Act (Cap. 164); Irrigation Act (Cap. 144A); Land Conservation and Improvement Act (Cap. 141); Land Development Act (Cap. 142); Meat Industry Act (Cap. 237); Pesticide Act (Cap. 157); Plant Quarantine Act (Cap. 156); Pound Act (Cap. 165); Protection of Animal Act (Cap. 169); Rewa Rice Limited Decree 1991; Stock Improvement Act (Cap. 162); Trespass of Animal Act (Cap. 166); Veterinary Surgeons Act (Cap. 257).

If there is an increase in use of the Land Use Decree 2010 with respect to leasing of iTaukei land it may have a major influence on agricultural development in the near future. It would also create the possibility of conflict between two regimes exercising power on the same area. However, currently land leasing under the decree is rare.

LAWS AND POLICIES FOR PREVENTION OF LAND DEGRADATION AND MANAGEMENT OF LANDS

Land degradation in Fiji is happening due to many direct causes, including deforestation, unsustainable agricultural practices, commercial livestock farming, reclamation of freshwater and mangrove swamps, and unplanned and uncoordinated urban development activities (Leslie and Tuinivanua 2010). Indirect causes such as high reliance on the sugar industry, lack of technological and infrastructural development, inefficient and unsustainable water resources management, and unplanned land use in watersheds and coastal margins are also contributing to land degradation (Leslie and Tuinivanua 2010).

Statutory conditions in lease documents include requirements for land conservation and prevention of land degradation, for example (Native Land Trust (Leases and Licenses) Regulations, 1984 reg 25):

- keeping the land in good and fertile condition;
- applying measures to prevent soil erosion that may include "strip cropping, terracing, contour planting, cover cropping, rotation of cropping, construction of drains or dams, and construction of fences";
- a condition prohibiting felling of "trees or clear or burn off bush or cultivate any land within a distance of twenty-four feet from the bank of a river or stream";
- a condition that "the lessee shall not clear, burn off or cultivate or permit excessive grazing of the top twenty-five per cent of the hills (as measured vertically) which have a slope exceeding twenty-five degrees from the horizontal".

The Land Conservation and Improvement Act 1953 established a Land Conservation Board consisting of representatives from agriculture, land, public works and forests departments as well as five members who do not hold any government post (Land Conservation and Improvement Act, 1953 s 3). The Land Conservation Board's functions include supervision over management of land and water resources, initiatives for stimulating public interest in the conservation of land and water resources, and providing recommendations to the government for legislative reform for conservation of land and water resources (Land Conservation and Improvement Act, 1953 s 5).

The Land Conservation Board has the power to issue conservation orders which may prohibit some listed activities if they are harmful to the conservation and improvement of land (Land Conservation and Improvement Act, 1953 s 7). In 2002 there was a proposal for reform of the Land Conservation Board, to improve functioning and resourcing of the Board. Currently however the Board appears to be inactive. For ensuring conservation of land and water resources, reform of the Board will be necessary.

Following reports and studies indicating that Fiji's uses of land and water resources were developing unsustainably, the Rural Land Use Policy for Fiji (RLUP) was formulated to guide the allocation and management of resources with respect to rurally based sectors. The most significant sector in this regard is agriculture, and it is agricultural activities with which RLUP is primarily concerned. The overarching aim of RLUP is to establish policy and legal frameworks which promote sustainable utilisation of land resources. A key aspect to achieving this goal is the review of all relevant resource management, planning, environmental and rural land-use legislation for consolidation into one cohesive legislative framework (Ministry of Agriculture, Sugar and Land Resettlement 2006, 6). Thus far, this consolidation has not occurred.

FORESTRY-RELATED LAWS AND POLICIES

Forest use and extraction of forest resources in Fiji is governed predominantly by the Forest Decree 1992, which repealed the Forest Act 1979 (Cap 150). Forestry-related activities are regulated through various licences, which must be obtained before any activities can occur. Logging licences (or 'forest concessions') can be issued for up to 10 years, with a possible extension to 30 years if the licensee undertakes to establish and operate processing facilities. Conditions can be imposed on timber licences to protect the relevant area in the best interests of good husbandry and silviculture. Another option is the annual logging licence, which is renewable and does not require the consent of the iLTB. A removal licence is required to be able to take forest produce from iTaukei land, forest or a nature reserve (Forest Decree 1992, s 8(1)(a)(ii)). Finally, a licence is needed to be able to plant any crops or trees in a forest or nature reserve (Forest Decree 1992, s 8(1)(a)(viii)).

Harvesting operations are also guided by the Fiji Forest Harvesting Code of Practice 2010. Applying to all timber harvesting operations which involve the sale of wood, the Code outlines practical procedures aimed at reducing the impact of logging so as to achieve best practice and minimise any adverse impacts. However, it lacks any legal basis for enforcement.

The Government of Fiji has explicitly recognised the need for the Forest Decree 1992 to be revised and updated (Ministry of Fisheries and Forests 2007). It needs to be more aligned with recent policy and legislative developments, such as the RLUP, the Environment Management Act 2005 (EMA) and the national REDD+ Policy 2011. The existing framework does not promote sustainable forest management, a deficiency highlighted in the Fiji Forest Policy Statement (FFPS) as requiring special attention (Ministry of Fisheries and Forests 2007). Reform of the Forest Decree envisaged by the FFPS encompasses, among other things: the establishment of a national planning system for forestry, in the form of permanent forest estates and forest management units; a legislative requirement for compliance with the Fiji Forest Harvesting Code of Practice 2010; and facilitation of a community forest management approach. Further, a major omission in both the Forest Decree and the Code is a requirement for the rehabilitation, replanting and management of logged-over areas.

Presently, there are three options by which forest areas may be protected, all of which revolve around the purpose of conservation. Pursuant to the Forest Decree, the Minister may declare any part of non-alienated iTaukei land a 'nature reserve', to be managed for the exclusive purpose of permanently preserving the land (Forest Decree 1992, ss 6–7). Customary landowners may not be willing to relinquish all land management rights to the Conservator of Forests, so this option may not be viable. Alternatively, a conservation lease can be entered into over iTaukei land pursuant to the iLTA (iTaukei Land Trust Act 1940, ss 7–9). Or finally, land of natural significance may be acquired, managed and regulated by the National Trust of Fiji, allowing the placement of permanent restrictions over the way in which such land may be used or developed by current and future landowners (National Trust of Fiji Act (Cap. 265), s 10). Fiji thus lacks a consolidated, comprehensive legal framework for preserving forest areas.

In light of the prevalence of wildfire, which is acting as a strong disincentive for agroforestry establishment, it is relevant to examine what laws Fiji has to prevent such fires. In Fiji, laws about fire-related offences are contained in the Crimes Decree 2009 (Decree No. 44 of 2009). It is an indictable offence, punishable by imprisonment for life, to wilfully or unlawfully set fire to any of the following: buildings or structures; vessels; commercial plantations of trees; or stacks of cultivated vegetable product (Crimes Decree 2009, s 362). Attempting to set fire to any of the above is punishable by imprisonment for 14 years (Crimes Decree 2009, s 363). It is a summary offence, punishable by imprisonment for 10 years, to wilfully or unlawfully set fire to any of the following: a crop of cultivated produce; a crop of hay or grass under cultivation; or any standing trees, saplings, or shrubs under cultivation (Crimes Decree 2009, s 364). Attempting to set fire to any of the above is punishable by imprisonment for 7 years (Crimes Decree 2009, s 365). These offences mirror, for the most part, sections 461–463 of the Queensland Criminal Code.

The Forest Decree 1992 also deals with this issue. It prohibits the burning of vegetation in a forest or nature reserve (Forest Decree 1992, s 8(1)(a)(v)). The Decree does not list the burning of vegetation as a purpose for which a licence can be obtained (Forest Decree 1992, s 9).

The Forest Decree is expected to be amended to provide a regulatory framework in accordance with the national REDD+ Policy 2011. This policy reflects Fiji's participation with the broader international community in the reduction of carbon emissions caused by deforestation and degradation. Guided by the Fiji Forest Policy Statement, the NCCP and the draft national REDD+ Strategy, the REDD+ program seeks to extenuate drivers of deforestation and forest degradation and promote drivers of forest expansion and conservation. In May 2011, a REDD+ national steering committee was established to coordinate and facilitate the implementation of the national REDD+ program. As part of implementation of the policy, it is envisaged that synergy between REDD+ and Fiji's Forest Policy will be achieved by "increasing agroforestry activities on non-forest lands (excluding wetlands/peatlands and indigenous palms)" (Fiji Forestry Department 2011).

ENVIRONMENTAL LAWS AND POLICES

Fiji has several pieces of legislation regulating activities which affect the environment. All of these give effect, to some degree, to international legal instruments to which Fiji is a party. The main legislation in respect to environmentally harmful activities, which occur on a substantial scale, is the Environment Management Act 2005 (EMA). Legislative frameworks for biosecurity, biodiversity and climate change are discussed in subsequent sections. As noted above, the Forest Decree will likely be amended in the near future to account for carbon rights and other concepts linked to Fiji's national commitment to reducing emissions from deforestation and degradation.

The EMA is the cornerstone of Fiji's management of environmentally harmful activities and operations. It was enacted following directions under Fiji's National Environment Strategy (NES) of 1993 to enact legislation for the management of resources and waste, the NES having identified resource sustainability as a key development constraint. Although enacted in 2005, the Environment Management Act 2005 did not come into force until 1 January 2009. At the international level, the EMA also gives effect to Fiji's obligations under international conventions including the United Nations Convention to Combat Desertification, the Convention on Biological Diversity (CBD) and the Convention on the Protection of Natural Resources and the Environment of the South Pacific.

The National Environmental Council (NEC), established by the EMA, is essentially a body of the Department of Environment, and is required to meet at least four times a year to coordinate the formulation, review and implementation of the NES and other environment-related policies. Thus, the NEC's functions and duties are broad, and it is entrusted with expansive powers to regulate environmental and resource management in Fiji.

In line with the NES, the purposes of the EMA are to ensure sustainability of natural resources, and to appropriately manage waste and pollution. The EMA lays down a framework which aims to ensure that serious and irreversible environmental damage is avoided, and to enhance the social aspects of development proposals. This framework is the environmental impact assessment (EIA) process, which is designed to enable the identification, evaluation and regulation of projects which may be environmentally harmful. The EIA process must be undertaken and a permit must be issued before any 'development activity' can commence; the process involves screening, scoping, preparation of an assessment report, report review and a final decision. The Waste and Pollution Control Administrator, which acts upon the advice given by the NEC, is authorised and empowered to issue permits if the reviewing body's decision is to allow the development. The following are offences under the EMA: commencing an unauthorised development activity; contravening any of the statutory duties which are part of the approval process; contravening a condition in the permit or approved EIA report; and intentionally providing false or misleading information in the approval process.

Where the development activity involves the clearing of mangroves to extract wood products, the Conservator of Forests, who is responsible for administering and enforcing the Forest Decree 1992, may require that an environmental impact statement be prepared for that proposal if it is likely to be significantly damaging (Environment Management Act 2005, s 27, Sch. 2). Proposals to amend the Forest Decree are expected to be considered by Cabinet to clarify the legal regime in protecting mangroves.

Environmental law reform in the context of development activities is on the horizon. For example, promoting better resource conservation is envisaged by the Roadmap for Democracy and Sustainable Socio-Economic Development 2010–2014. As part of the government's broad socioeconomic reforms—covering electoral and parliamentary issues, public service, land, education and health—the Roadmap highlights the lack of adherence to the EMA and the absence of an environmental statutory authority as impediments to efficient and sustainable land use and management (Ministry of National Planning 2009). Similarly, Fiji's participation in the REDD+ program will eventually see climate change issues integrated into various sectors' legislative frameworks.

BIOSECURITY AND BIODIVERSITY LAWS AND POLICIES

The NES also identified biodiversity protection as an important environmental issue in need of action by Fiji. In September 2007, the government formally published the Fiji National Biodiversity Strategy and Action Plan (FNBSAP) after its endorsement by Cabinet in 2003. This was the starting point for Fiji's compliance with its obligations under the International Convention on Biological Diversity (CBD). The CBD requires the development and implementation of national strategies to conserve and use the components of biological diversity in a sustainable manner; to integrate biodiversity policy into relevant sectoral or cross-sectoral plans and programs; and to monitor and periodically report on the status of biodiversity in the environment.

As part of the implementation process, the FNBSAP Implementation Framework (2010–2014) was formulated in 2010. The implementation framework identified seven key thematic areas for priority actions: forest conversion management; invasive alien species; inshore fisheries; coastal development; species conservation; protected areas; and inland waters.

National legislative implementation of biodiversity management and protection occurred in the form of the Biodiversity Promulgation 2008. The Promulgation was enacted to manage and control the introduction, establishment and spread of animal and plant pests and diseases. It established the Biosecurity Authority of Fiji (BAF), which is tasked not only with protecting the agricultural sector from animal and plant pests and diseases, but also with facilitating access to viable agro-export markets and ensuring compliance of Fiji's agro-exports with overseas market requirements. The BAF operates from Fiji's three major ports of entry: Suva Wharf, Nadi International Airport and Lautoka Wharf.

As well as obligations under the CBD, the Endangered and Protected Species Act 2002 (EPSA) gives effect primarily to Fiji's international obligations under the Convention on International Trade in Endangered Species (CITES), the aim of which is to ensure that animals and plants in international trade are not exploited unsustainably. This is implemented through a licensing system which prohibits the export and import of numerous species without a permit. The ESPA establishes two statutory bodies: the CITES Management Authority (CMA), and the Scientific Authority (CSA). The CMA coordinates the national implementation of CITES and manages the licensing system, while the CSA advises the CMA on the issuance of permits and the effects of trade on species.

OTHER POLICES RELEVANT TO AGROFORESTRY

The Roadmap for Democracy and Sustainable Socio-Economic Development 2010–2014 articulated a vision of "sustainable community livelihoods through food security and competitive exports" (Ministry of National Planning 2009). This vision included the adoption and implementation of an integrated land and water resources management plan (Ministry of National Planning 2009), along with a restructure of the sugar industry and non-sugar agricultural industries, both for commercial development. In respect to forestry, the Roadmap acknowledged that there is "potential for large denuded forest grasslands to be converted into forest plantations of sandalwood (Santalum yasi) and teak (Tectona grandis) plantations" (Ministry of National Planning 2009). The Roadmap also identified the following development constraints and challenges for the forestry sector:

- absence of comprehensive regional and national land-use plans;
- limited protection and enforcement for conservation, especially in native forests;
- inadequate knowledge of forest resources;
- poor fire protection capabilities and procedures;
- institutional weaknesses and difficult bureaucratic processes;
- outdated forestry legislation; and
- absence of detailed forest management and harvesting plans.

One relevant strategy in this regard was to "Undertake research focused on timber utilization and product development to diversify the export base".

Consisting of 73 objectives and 266 strategies, the National Export Strategy of 2006 was directed at broadening Fiji's global export base by improving the competitiveness of its products and services. The six major sectors identified as providing greatest potential for competitive advantages were agro-business, forestry, marine products, mineral water, information and communication technology and audio-visual. A key constraint identified by this strategy was the need to reduce the cost of business in Fiji, a key strategy being stronger partnerships between the public and private sectors for more coordinated and cohesive development.

FIJI 2020 AGRICULTURE SECTOR POLICY AGENDA 2014

In response to concerns over rising food import bills and diminishing exports (particularly sugar), the Department of Agriculture formulated its Agriculture Strategic Development Plan 2010–2012 (ASDP). Outlining eight priority strategic goals and eight key development targets as a framework for promoting the competitiveness of Fiji's agricultural export markets, the ASDP advocates a demand-driven approach towards raising production levels from semi-commercial to commercial, with the immediate purpose of increasing market access opportunities and services for producers in rural areas and outer islands.

The Ministry of Agriculture released the Fiji 2020 Agriculture Sector Policy Agenda in August 2014. The Agenda aims to establish a diversified and economically and environmentally sustainable agriculture sector by 2020. It also contributes to the national goal of sustainable community development envisaged in the Roadmap by directing the consolidation of agriculture legislation and policy. The impetus for this Agenda was governmental recognition of the need for modernisation and consolidation of Fiji's agriculture, forestry and marine resources to achieve productive and commercial-scale agriculture.

The development framework by which the Agenda's goals are to be achieved is structured around the following five pillars:

a. To build modern agriculture in Fiji as an organised system of producing, processing and marketing crops, livestock and aquaculture products.
b. To develop integrated production, processing, energy and transport infrastructure support system for agriculture.
c. To improve delivery of agriculture support services.
d. To enhance capabilities to generate, fund and secure investment through foreign investment, private–public partnerships, and other innovative business arrangements.
e. To improve project implementation and policy formulation capability within the Ministry of Agriculture and its partner institutions.

In terms of implementation, which is to occur between 2015 and 2020, the Agenda foresees consolidation of the agriculture sector's 33 pieces of legislation into an omnibus Act. This is a much more significant reform than that set out in the ASDP, which sought merely to review the various pieces of legislation and ensure there were no policy conflicts between them (Ministry of Agriculture 2014). This omnibus Act will cover a broad range of agriculture-related matters, including: adjustment of the proposed infrastructure; rural transformation; industry-focused approaches toward land ownership and leasing; and the use of water resources. A mid-term review, carried out for policy adjustment in conjunction with the implementation phase, will occur in 2017.

The Agenda explicitly addresses agroforestry. In particular, it recommends adoption of sloping agricultural land technology and line planting

(Ministry of Agriculture 2014). Agroforestry is also considered the 'ultimate solution' to addressing problems stemming from poor land-use practices. It is envisaged that agroforestry will be comprehensively addressed in the proposed omnibus agriculture Act (Ministry of Agriculture 2014).

INSTITUTIONAL COOPERATION AND POLICY ISSUES

In the inception workshop of this research project, it was stated that there is a serious lack of coordination between government departments for promoting agroforestry. Promotion of agroforestry will require cooperation between agriculture and forestry departments as well as other government departments, for example livestock, land, sugar and fisheries departments. As observed by Mr Eliki Senivasa (Deputy Conservator of Forest, Fiji), agroforestry is a grey area and there are serious policy and implementation gaps, as well as confusion over responsibilities. The ultimate result is failure of the policy initiative. To solve this will require a harmonising of policy (see Table 2).

The Fiji Forest Policy Statement 2007 clearly identifies the Forest Department as the leading organisation for promoting agroforestry. However, despite identifying agroforestry as the ultimate solution for forestry and agriculture sectors in upland communities, the Fiji 2020 Agriculture Sector Policy Agenda 2014 does not readily provide any guidance for cooperation and coordination of forestry and agriculture departments in promoting agroforestry. In reality agroforestry cannot be promoted without joint efforts by these two departments as well as cooperation from other relevant government departments. To achieve the policy objectives under the 2007 Forest Policy and the 2014 Agricultural Policy Agenda, a joint national strategy establishing a council for cooperation for agroforestry including senior officials from relevant departments may be needed. The proposed agroforestry strategy may be treated as an implementing instrument under forestry and agriculture sector policies.

There is a real need for cooperation between the relevant government departments. The Fiji 2020 Agriculture Sector Policy Agenda provides a vision and framework for agricultural development. Several statutory authorities play prominent roles in developing Fiji's agricultural sector. Most important of these is the Ministry of Agriculture. The Ministry has a number of divisions including for agricultural extension, land resource planning and development, and land and water. Between 1998 and 2010, the Coconut Industry Development Authority (CIDA) was tasked with developing and regulating the coconut industry, including policy formulation and implementation, and given broad functions and powers under statute (Coconut Industry Development Authority Act 1998, ss 8-10). With the passing of the Coconut Industry Development Decree in 2010, however, the CIDA was dissolved and its duties, functions and powers transferred to the Ministry of Agriculture. The Biosecurity Authority of Fiji (BAF) is tasked with protecting Fiji's agricultural sector from the introduction and spread of pests and diseases, facilitating access to viable agro-export markets, and ensuring Fiji's agro-exports comply with overseas market requirements. The iLTB and Land Use Unit are responsible for each of their respective statutory regimes involving the leasing of iTaukei land, which is often in respect to agricultural development.

The Forestry Department, under the Ministry of Fisheries and Forests, is responsible for Fiji's forest sector. In particular, the Forestry Department is responsible for policy, legislative matters, and administration and enforcement of forest legislation and regulations. The Conservator of Forests oversees administration and enforcement of the Forest Decree 1992, including the issuing of licences (Forest Decree 1992, s 3). Under proposed amendments to the Forestry Department, the Conservator of Forests will also oversee approvals for REDD+ projects and activities.

Agroforestry is dealt with under the auspices of the Ministry of Agriculture and Ministry for Fisheries and Forests. According to the Fiji 2020 Agriculture Sector Policy Agenda the country's agricultural, forestry and marine resources are facing numerous threats, particularly the threat of pollution and climate change (Ministry of Agriculture 2014). Despite an agrarian society, the country is increasingly reliant on imported food and the food security of the country is threatened (Ministry of Agriculture 2014). The Policy also states that the agricultural sector may play a vital role in ensuring energy security by providing "the feedstock for biofuels to reduce the country's petroleum fuel importation bill" (Ministry of Agriculture 2014). All these challenges and opportunities clearly indicate the need for a cooperative policy initiative for promoting agroforestry. The current ad hoc management and policy regime for agroforestry is not enough.

Table 2. Promoting agroforestry: major policy regimes

Fiji Forest Policy Statement 2007	Fiji 2020 Agriculture Sector Policy Agenda 2014
The Government will promote and provide support to the development of agroforestry systems as a means to enhance food and forest production on areas cultivated for crop production by way of planting and integrating suitable forest trees into their existing farming system. The Forestry Department (FD) in partnership with resource owners will develop and promote agroforestry where resource owners wish to rehabilitate degraded land, or to improve the mix of income and other benefits from their land.	A principal operating system to be employed in mass based modernisation of the agriculture sector in Fiji is agroforestry in the upland areas where the forestry and agriculture sectors converge. Adoption of climate change agriculture in Fiji can be introduced through conservation agriculture. Agroforestry is one option. Incorporating small livestock, such as poultry, sheep, and goats into the farming system brings additional income and food security in preparation for climate change. Agroforestry is an approach that also strengthens agriculture and forestry convergence and it also becomes an operating system in the RTCs [Rural Transformation Centre] in upland communities in Fiji.
1. The FD will conduct research and studies to identify/develop appropriate and reliable agroforestry systems suitable for local environments and that will provide regular returns to the communities involved. 2. The FD will take the initiative to establish agroforestry farm models in cooperation with other public agencies and NGOs and ensure that new and appropriate technologies are applied. 3. The FD will provide appropriate advice, assistance and technologies to communities in order to improve and sustain their livelihoods, and to strengthen and promote their socioeconomic, environmental and cultural values. 4. The FD will conduct awareness and education campaigns for landowners/resource owners to emphasize the importance of agroforestry for the improved socioeconomic wellbeing of the communities.	The promotion of agroforestry will be a policy objective to achieve the core objective of consolidating lands composed of smallholder farms under modern organized system of producing, processing, and marketing crops, livestock, and aquaculture products. Agroforestry • Develop sustainable commercial use of the forest trees using selective harvesting • Promote Sloping Agriculture Land Technology and Line Planting Technology • Develop agroforestry both for food and energy feedstock
The FD will improve coordination between government departments related to the rural development and elaborate extension packages for dissemination of effective forestry and agroforestry information which shall be used by the public service and non-governmental development agencies. The FD will co-operate with other Government ministries and authorities, to implement the various land use planning, agroforestry and conservation strategies contained in this forest policy; for example, the Ministry of Environment, Ministry of Agriculture.	Forestry and Agriculture Convergence The *physical convergence of the forestry and agriculture sectors* are in the upland communities that are now under population pressure for agriculture production. Poor land use practices, however, affect the long term soil fertility due to erosion and continuous crop cultivation. The water and river systems are also affected. *Agroforestry is the ultimate solution to address these problems.* This strategy eventually becomes the operating system for the forestry and agriculture convergence. Furthermore, this convergence must be well defined technically in the proposed Omnibus Agriculture Law.

CONCLUSIONS

This paper identifies a number of critical issue in the promotion of agroforestry. The first is, fundamentally, the lack of a joint agroforestry strategy by relevant government departments. This may come as little surprise, given that very few countries have such policies. Nevertheless, the lack of such a policy calls into question the effectiveness of existing policies that touch upon agroforestry, particularly those relating to agriculture and forestry. The second, which is related to the first, is the significant overlap of agroforestry-related activities across several government departments. Coordination and cooperation between these departments is wanting. The third is the destructive effect wildfires are having on land and the efforts of those seeking to engage in productive land uses. Another major and related issue is land degradation. Against this backdrop, this paper presents an overview of existing laws and policies in Fiji relevant for agroforestry. Finally, below are some policy recommendations for promotion of agroforestry in Fiji.

1. A national strategy for agroforestry should be developed, that clearly identifies responsibilities for each relevant department and promotes cooperation.
2. Initiatives should be taken to ensure the security of tenure for farmers on agricultural lands and to build their confidence regarding livelihood security, thereby encouraging them in long-term investment and commitment in sustainable agricultural practices including agroforestry.
3. Reform and revitalisation of the Land Conservation Board is needed to ensure proper functioning of the Board including adequate human and financial resources.
4. The Fiji 2020 Agriculture Sector Policy Agenda states "The MOA [Ministry of Agriculture] is currently responsible for over 33 pieces of legislation. It is foreseen that all the acts specified under the ministerial assignment must be reviewed and be ensured that there is no conflict between policy interpretations of existing acts. The consolidation of the law into an omnibus legislative act provides a better structure for common understanding so that anything that is in line with agriculture development can be put together in just one piece of legislation." The proposed omnibus legislative act should include provisions for promotion of agroforestry.
5. In some countries a legal framework has been developed for managing and promoting community agroforestry/social agroforestry development in partnership with government and farmers' groups. Fiji may explore this option through a feasibility study to encourage indigenous landowning units to engage in community agroforestry projects on a public–private partnership basis.

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13. Policies and laws for promoting sustainable agroforestry in Vanuatu

Md Saiful Karim, Alexander Button-Sloan and Mohammad Alauddin

Abstract

An appropriate legal and policy framework is important for the development of agroforestry. This paper identifies and discusses some of the key legal and policy issues arising with respect to Vanuatu's move to develop sustainable agroforestry. Fundamentally, there is a lack of a joint agroforestry strategy for relevant government departments, and this challenges the effectiveness of existing policies that touch upon agroforestry, particularly those relating to agriculture and forestry. There is a significant overlap of agroforestry-related activities across several government departments, and coordination and cooperation between these departments is wanting. Finally, alienation of local communities from their land is a major hurdle for agroforestry development in Vanuatu. This paper suggests that the government should take immediate initiatives for management of agriculture leases, particularly regarding lease to foreigners; and support for interagency cooperation is needed for promotion of agroforestry.

INTRODUCTION

There is significant potential for further development of agroforestry in Vanuatu. Any major initiative for promotion of agroforestry will however require an enabling legal and policy framework. Vanuatu does not have a separate law, policy or strategy for agroforestry. Laws relating to land systems and tenure, agriculture, land degradation, forestry, environment, biosecurity and biodiversity are directly or indirectly relevant for agroforestry. Policies for forestry and agriculture are directly relevant for agroforestry, while other policies such as those dealing with climate change and environment are also relevant. This paper presents an overview of some of these relevant laws and policies (Table 1). The paper argues that although there is strong support for agroforestry in the agricultural and forestry polices, practical efforts and coordination for implementation of these broader policy objectives is lacking.

LAND LAWS AND POLICIES

One of the major problems in the development of agroforestry in Vanuatu is conversion of agricultural land for other purposes particularly by foreign landowners. "Land booms resulting in the alienation of customary owners from their lands have been a key feature of Vanuatu's historical and ongoing interactions with foreign powers" (Daley 2009).

Table 1. Vanuatu laws discussed in this paper.

Alienated Land Act 1982	Forestry Act 2001
Community Conservation Areas (Environmental Protection and Conservation) Act 2003	Forestry Rights Registration and Timber Harvest Guarantee Act 2000
Constitution (Sixth) (Amendment) Act No. 27 of 2013	Freehold Titles Act 1994
Constitution of the Republic of Vanuatu 1980	Land Leases Act 1983
Environmental Protection and Conservation Act 2003	Land Reform Act 1980
Foreshore Development Act 1976	Meteorology Act 1989

Loopholes in the land laws have served the interests of foreign investors who alienated the land from indigenous landowners and thereby diminished the potential of agroforestry or other agricultural development by local communities (Daley 2009).

Presently, land tenure in Vanuatu is a collection of laws—customary and legislated—which have been affirmed or enacted since independence in 1980. As part of Vanuatu's independence, the newly adopted Constitution established a framework for entrenching the rights of customary landowners with respect to land use and ownership.

Until recently Vanuatu did not have any national land-use legislation. Adoption of the Constitution of the Republic of Vanuatu, as part of Vanuatu's independence in 1980, reinstated customary ownership at the forefront of national land policy. However, the constitutional provisions reflect broad policy commitments to provide a framework for more comprehensive reform. The Constitution explicitly envisaged that this framework would be implemented in a more detailed package of legislation—the National Land Law (NLL) (Constitution of the Republic of Vanuatu 1980, Art 76). This deferral was a deliberate drafting choice; the drafters considered that ambiguities and uncertainties as to the rights and responsibilities of customary landowners would be addressed by the NLL (Lunnay et al. 2007). Various pieces of legislation enacted immediately after independence, including the Land Reform Act 1980 and the Land Leases Act 1983, were not long-term solutions, and were intended to serve merely as interim regulatory measures.

Adoption of the Constitution in 1980 brought about significant changes to land tenure in Vanuatu. The relevant articles contained in Chapter 12 of the Constitution were as symbolic as they were profound. In 1980, about two-thirds of land was owned by foreigners and the catalyst for Vanuatu's independence was the agitation by indigenous citizens to reclaim their land (Farran 2010). Pursuant to Article 73, the alienation of land under the Anglo-French Condominium government was effectively overturned, ownership of all land in Vanuatu returning to its customary owners (Constitution of the Republic of Vanuatu 1980, Art 75). The Constitution entrenches the primacy of this customary tenure, providing that it is the customary rules which determine land ownership and use in Vanuatu, and that perpetual ownership of land rests solely with Vanuatu's indigenous citizens (Constitution of the Republic of Vanuatu 1980, Arts 74, 75). All land transactions between ni-Vanuatu and either non-citizens or non-indigenous citizens require Government consent (Constitution of the Republic of Vanuatu 1980, Art 79). The establishment of the National Council of Chiefs is also provided for under the Constitution, although in a non-mandatory consultative role which is also not authoritative (Constitution of the Republic of Vanuatu 1980, Art 30).

In 2014, national land law reforms were achieved after a broad consultative process that commenced with the National Land Law Summit of 2012. These consist of amendments to the Constitution, the Land Reform Act and the Land Leases Act, as well as enactment of the Customary Land Management Act. Together, the new laws introduce significant changes to existing frameworks for dealing with state and customary land. They remove ministerial powers with respect to customary land dealings, and require the consent of the customary owner group before leases are granted over customary land. However, given that much of the reform consists of changes to existing laws, it is necessary to first provide an overview of the framework in place prior to the 2014 amendments.

Since independence, in response to growing public concern regarding the management and administration of land-related matters, Vanuatu's first ever National Land Summit was held in September 2006. The Summit was hosted by the Ministry of Lands and Natural Resources (MLNR), which comprises the Department of Lands, Survey and Records (DLSR) and the Environment Unit and bears overall responsibility for developing national land legislation and policy. The summit culminated in 20 resolutions being adopted under the theme 'Sustainable land management and fair dealings to ensure that social and economic progress takes place in an environment where there is always fairness and stability'. These resolutions mostly addressed existing ambiguities surrounding the nature of customary land tenure; the lack of protection of customary ownership interests in the context of land development; and the lack of clearly defined responsibilities in and among government administrators.

Vanuatu's Land Sector Framework 2009–2018 (LSF) was developed by the Ministry of Lands as a comprehensive framework for the implementation of the land sector reforms adopted in the NLS. The LSF is therefore intended to be more than just a blueprint; it outlines key strategies for each of the five recognised focal points of concern for the land sector (Ministry of Lands 2009). Establishment of a multi-stakeholder Vanuatu Land Governance Committee is envisaged for national-level oversight of these concerns, including bearing responsibility for planning and reviewing the LSF (Ministry of Lands 2009).

The five focal points are: enhancement of land governance; engagement with customary groups; ensuring access and tenure security for all groups; improvement of delivery of land services; and making the land sector productive and sustainable. Whereas the latter two concerns relate to economic development, the first three show the centrality of customary tenure to law and policy development. Enhancement of land governance emphasises the need to empower customary landowners by allowing them to assume their traditional responsibilities and to participate actively in the land governance process (Ministry of Lands 2009). This will involve reviews and improvements to land legislation, including the alignment of legislation with constitutional principles, to ensure accountable, transparent and fair dealings in land (Ministry of Lands 2009). Engagement with customary groups is similarly underscored by the recognition that the land tenure system must develop in accordance with, and in consultation with, customary groups. In addition to establishing important community programs, services and communication mechanisms aimed at supporting customary groups in land dealings, this includes the recording and registration of customary land ownership (Ministry of Lands 2009). Ensuring access and tenure security stemmed from the lack of clarity in land-based rights, practices and obligations. In particular, the focus areas in need of clarity are customary land, common property resources, cultural and heritage sites, and leased areas (Ministry of Lands 2009).

At independence, with strong demand among indigenous citizens to reclaim their land, there was still a large contingent of freehold interests over customary land. Thus, the Government considered it necessary to implement interim land right measures. The Land Reform Act 1980 (LRA) allowed these 'former title-holders' to remain occupying the land either until a lease agreement was negotiated with customary owners, or until they accepted compensation payment for improvements to the land (Land Reform Act 1980, s 3). To gain these rights, alienators had to apply to the relevant minister to be recorded on the Register of Alienators (Alienated Land Act 1982, ss 2, 8, 9).

Provision is also made in the LRA for the Minister of Lands to have power to grant leases to alienators on behalf of customary owners if the land is neglected or inadequately maintained, or if ownership is in dispute (Land Reform Act 1980, s 8). Consistent with the constitutional requirement under Article 79, all leases require consent of the government (Land Reform Act 1980, ss 6-7).

Articles 80 and 81 of the Constitution confer power on the government to legislate, respectively, for it to acquire "land in the public interest" and for it to acquire customary land "for the purpose of land redistribution". The Land Acquisition Act 1982 (LAA) was enacted to spell out the procedures to be followed by the government in exercising these powers. There is an inherent inconsistency, however, between the constitutional power to acquire customary land and the supposed inalienability of customary land according to customary law.

The Land Leases Act of 1983 (LLA) established a system for the creation and transfer of, and payment for, leasehold titles. Although not an NLL as such, it still forms the basis of most dealings with customary land today. Based loosely on the Torrens system of indefeasibility (meaning 'cannot be defeated, revoked, or made void'), the scheme makes registration a prerequisite for validity and enforcement of leases (Land Leases Act 1983, s 15). Leases are subject to 'implied agreements' which effectively impose obligations on lessees (Land Leases Act 1983, ss 40A-41) while a lessor may forfeit the lease for a breach of its conditions (Land Leases Act 1983, s 46).

Lease terms are capped at 75 years (Land Leases Act 1983, s 32). Amendments to the LLA were passed in 2003, 2004 and 2006 to improve the returns earned on leases by customary owners and the government. A major omission in the LLA, and in Vanuatu's land tenure system generally, is a mechanism for recording and registering customary land ownership.

The Physical Planning Act 1986 (PPA) is the sole law governing land-use planning in Vanuatu. It allows local councils to designate 'physical planning areas' and formulate plans specifying when permission is required for development in those areas. It focuses on local planning processes only, not at the provincial or national levels, and does not provide for a land classification scheme. The LSF emphasises the need for reform in physical planning and development for the productivity and sustainability of the land sector (Ministry of Lands 2009).

The restoration of customary ownership under Article 73 of the Constitution applies only to rural lands; urban land, mostly owned by the colonial governments, was vested in the government as 'public land' at independence (Land Reform Act 1980, ss 1, 9). After an unsuccessful attempt, via the Urban Lands Act 1993, to free up more urban land with a view to encouraging investment, the government enacted the Freehold Titles Act 1994 (FTA). The FTA allows indigenous citizens to acquire a freehold interest if they hold an unconditional head-lease registered under the LLA (Freehold Titles Act 1994, s 3). There is an explicit inconsistency between this provision and Article 74 of the Constitution, which effectively abolished the concept of freehold land in Vanuatu, although reports indicate that the provision has not been invoked (Lunnay et al. 2007).

An overall reform to existing land laws was undertaken in 2014. This represents the culmination of extensive provincial consultations carried out after the National Land Law Summit in 2012. It applies to all existing customary land leases, and to all dealings of state-owned lands.

The amendments move decision-making control on the grant of leases over customary land out of governmental hands and to the customary landowners. Previously, this power lay exclusively with, and at the discretion of, the Minister of Lands. Now, the Minister may only become involved in dealings with customary land on a purely formalistic basis on the basis of recommendations from the independent body established to safeguard the interests of customary landowners—the Land Management Planning Committee (LMPC). The custom group may withhold consent for the grant of a commercial lease (Land Reform Act 1980, s 6J).

There is also an extensive process that must be adhered to if the lease is not to be deemed void and of no legal effect. Before being able to even negotiate a lease with the custom owners, commercial developers must successfully apply to the LMPC for a negotiator's certificate. The LMPC must provide a recommendation to the minister before the minister can issue such a certificate. The LMPC must be satisfied that all members of the custom owner group consent to negotiating with the developers (Land Reform Act 1980 s 6I). The decision of the custom group to withhold their consent to negotiate is final—it cannot be challenged by anyone, including the minister. A recommendation from the LMPC, and the informed consent of the custom owner group to the terms of an agreed lease after their negotiations with the developers, must be the result of a specific statutory consultation process which, if not followed properly, results in any agreed lease being void and of no legal effect (Land Reform Act 1980). A custom owner may make a complaint to the newly established Land Ombudsman if not satisfied the process was properly adhered to.

In practice, a major issue with respect to dealings of customary land has been disputes as to the identity of the customary landowners, and as to land use rights. While the Land Reform Amendment Act 2014 provides a process for finding out who these landowners are, the forum for determining this and land use disputes as a matter of law has traditionally been the state courts.

With the insertion of the new Article 78 into the Constitution (Constitution (Sixth) (Amendment) Act No. 27 of 2013) coupled with the enactment of the Custom Land Management Act 2013, the 'nakamals' now have exclusive jurisdiction to determine the rules of custom which form the basis of ownership and use of land in Vanuatu. The decisions of these customary tribunals are binding in law, and are not subject to appeal or any other form of review by any court of law.

FORESTRY-RELATED LAWS AND POLICES

The Forestry Act 2001 regulates forestry operations conducted for commercial purposes. Commercial operations require both a specific type of agreement and a specific type of licence. Subject to limited exceptions, the Act also imposes a ban on the export of logs (Forestry Act 2001, s 61). Forestry-related activities carried out by customary landowners for sale to ni-Vanuatu in accordance with customary usage are explicitly excluded from the Act's operation, and these are instead regulated by the customary laws pertinent to the specific land in question (Forestry Act 2001, s 3).

The Act outlines an agreement–licence regime. It is an offence to carry out operations without either of these (Forestry Act 2001, s 70). The three kinds of agreements are the timber rights agreement (TRA), timber permit and forestry lease. Timber permits, which can be issued for up to one year, are issued where the value of timber does not justify the expense of a TRA. The TRA, on the other hand, can remain in force for 10 years and is renewable. The Forests Board of Vanuatu is responsible for consultation with customary landowners and supervision of TRA negotiations. Alternatively, a 75-year forestry lease can be entered into with customary landowners, after having obtained necessary approvals under the LRA.

The four types of licences are the timber licence, mobile sawmill licence, sandalwood licence and special licence. The mobile sawmill licence, the most commonly issued licence, is also regulated by the Forestry (Control of Mobile Sawmills) Regulations (Cap. 276). While special licences are something of a 'residual' licence—issued for operations where the other licences are not practicable or desirable—they are mostly used to authorise either land clearing for agricultural purposes or hazard removal. Special licences are issued for up to a year (Forestry Act 2001, s 48(3)(a)).

While all commercial forestry operations are subject to the Code of Logging Practice 1998, which is given legal force under the Act (Forestry Act 2001, s 43), operations may also be subject to other environmental obligations or processes. For example, the Forestry Act empowers the minister to declare certain areas of land as conservation areas in which commercial forestry operations are prohibited (Forestry Act 2001, ss 50–52). Alternatively, under different legislation but with similar effect, the Department of Environmental Protection may declare an area as a community conservation area (Community Conservation Areas (Environmental Protection and Conservation) Act 2003). In respect to biodiversity protection, the Forestry Act also empowers the minister to prohibit the logging of specifically protected plant species without an express licence. Mangroves, which are the subject of extensive deforestation for timber, are not specifically protected under legislation, but all developments on foreshore areas containing mangroves must be assessed and approved under the EIA process outlined in the EPCA (Environmental Protection and Conservation Act 2003, s 12A; see also the Foreshore Development Act 1976). Finally, areas can be declared as a national park or nature reserve under the National Parks Act 1993, although reports suggest this legislation has apparently conflicted with customary land tenure, and will therefore likely be repealed.

The Vanuatu Forest Policy 2013–2023 provides a framework for the development and management of the entire forestry sector. The overarching vision of the policy is equitable, sustainable and profitable management and conservation of Vanuatu's trees and forests. A key reform is to amend the Forestry Act 2001 for integration with other forestry-related legislation and the legislation regulating other sectors. The policy also envisages the development of a national biodiversity strategy and action plan (Department of Forests 2011).

This policy also outlined specific objectives regarding the need for Vanuatu's forests to be sustainably managed and developed through integration of climate change mitigation issues into sector planning and activities. As part of Vanuatu's international commitment to reduce emissions from deforestation and forest degradation, which began in 2006 with the Vanuatu Carbon Credits Project, Vanuatu is proposing to implement its national REDD+ scheme on a programmatic basis. Accordingly, REDD+ programs and activities will be developed nationally involving the integration of REDD+ with land use and sectoral policies. Applying the concept of sustainability to the need to reduce forest degradation and greenhouse gas emissions from forests is aimed at enhancing resilience against the adverse effects of climate change. Objectives include commitments to proactively incorporate climate change adaptation and mitigation challenges and opportunities, and to embrace climate change mitigation and emissions reduction through reducing deforestation and degradation, and increasing afforestation and reforestation (Department of Forests 2011).

Vanuatu currently lacks a clear and specific legislative framework dedicated to REDD+ activities, a notable omission which was identified in the Vanuatu Forest Policy 2013–2023 (Department of Forests 2011). As an indirect measure, the licences issued under the Forestry Act usually include reforestation conditions which can be enforced against the licensee (Forestry Act 2001, s 37(2)). While there is legislation which provides for forest carbon rights (Forestry Rights Registration and Timber Harvest Guarantee Act 2000), in practice this Act is not used, and in any event does not address the ownership of carbon rights on unleased customary land. This latter point will likely be a source of much difficulty, given that ownership of carbon rights will be determined according to customary laws of the specific land in question; and these laws could vary significantly between land areas.

ENVIRONMENTAL LAWS AND POLICES

Vanuatu's legal framework for the conservation and management of the environment of Vanuatu is contained in the Environmental Protection and Conservation Act 2003 (EPCA). This piece of legislation requires all developments (excluding residential and custom structures) that are likely to cause "significant environmental, social and/or custom impacts" to be subject to the environmental impact assessment (EIA) process. This process is undertaken to obtain an approval to proceed with the development, and the EPCA prescribes certain offences related to developments which proceed without approvals, the assessment process itself, and the terms and conditions of approvals. The Department of Environment and Conservation (DEC) administers the EIA process and is empowered to ensure all developments and activities comply with the EPCA. Despite the powers afforded to the DEC, however, its officers are not provided a right of entry to development land in the course of administering their duties under the EPCA. In 2004, the DEC was subject to an adverse award of VT 750 million in damages for claims of negligence, injurious falsehood, defamation and breach of confidence, made by a developer of a tourist resort (Lunnay et al. 2007).

The EPCA also regulates the protection and management of biodiversity and conservation areas. As part of Vanuatu's implementation of the Convention on Biological Diversity (CBD), the EPCA established the Biodiversity Advisory Council to oversee the legislative scheme which requires persons to apply for and obtain permits to undertake biodiversity prospecting. Similarly, the EPCA provides for certain customary land to be declared a community conservation area (CCA) after both identification of the site as having national biodiversity significance and the consent of customary landowners being given. CCAs are areas which fall into one of the following categories: possesses unique genetic, cultural, geological or biological resources; constitutes the habitat of species of wild fauna or flora of unique importance; or merits protection under the Convention Concerning the Protection of World Cultural and Natural Heritage.

The Vanuatu Forest Policy 2013–2023, discussed in detail below, reinforced the importance of protection of biodiversity and conservation areas. For example, as part of the objective of actively managing and protecting 30% of Vanuatu's natural forests, the VFP recognises the need to enforce the protection status of CCAs (Department of Forests 2011). In respect of biodiversity, the VFP provided direction for the development of a national biodiversity strategy and action plan as part of the need to protect and manage endemic, rare, threatened and endangered species in forest environments (Department of Forests 2011).

CLIMATE CHANGE LAWS AND POLICES

Vanuatu lacks legislation specifically implementing a national climate change response. Existing legislation includes the National Disaster Act 2000 (NDA) and the Meteorology Act 1989 (MA). Climate change actions are peripheral in these. The NDA provides a scheme for disaster response, including mechanisms for authorising officials to declare a disaster and to exercise relevant powers, while the MA tasks the Vanuatu Meteorological Service with, amongst other things, the responsibility of issuing severe weather warnings (Meteorology Act 1989, s 6). The Forestry Act 2001, which is discussed in greater detail below, provides a basic legal framework for the implementation of climate change mitigation actions in the forestry sector as part of Vanuatu's REDD+ program and National Forest Policy 2013–2023.

The Seventh Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2001 resolved to support least-developed countries (LDC) in the preparation, implementation and cost of national adaptation programs of action (NAPAs). The resolution was underpinned by the recognition that LDCs have a low adaptive capacity with respect to climate change, rendering them particularly vulnerable to adverse effects. By identifying and communicating the adaptation needs and actions for priority sectors, NAPAs provide a framework for introducing measures to strengthen capacities to deal with and reduce vulnerabilities to climate change. As an LDC signatory to the UNFCC, Vanuatu was eligible for provision and funding of a NAPA.

The NAPA for Vanuatu was developed in 2007. Climate change vulnerabilities were mostly identified as relating to the adverse effects of coastal erosion, cyclones and flooding on agricultural and livestock production, water facilities and major infrastructure. Projects given priority status were listed in the following descending order: agriculture and food security; water management; sustainable tourism; community-based marine resource management; and sustainable forestry management. Against this backdrop, 11 adaptation priority strategies were formulated, and these were mostly related to agricultural development and livelihood promotion. However, the NAPA provides no specific action plan for implementation.

The second (and latest) draft of Vanuatu's National Climate Change Adaptation Strategy 2012–2022 (NCCAS) was released in July 2011. The purpose of the NCCAS is to guide the development and implementation of climate change mitigation actions in the land-based resource sectors of forestry, agriculture, water, livestock and biodiversity. Building on existing frameworks and policies such as the NAPA and the Disaster Management National Action Plan, it provides a programmatic- rather than project-based focus for climate change adaptation into ni-Vanuatu core sectoral activities. After examining existing adaptive capacities, regional and national policies and institutional structures relevant to climate change, the NCCAS outlines and recommends sector-specific action plans for near-future implementation.

VANUATU AGRICULTURE SECTOR POLICY 2015–2030

Until recently, Vanuatu has been without a national agricultural policy. Under the auspices of the Department of Agriculture and Rural Development (DARD), the Agricultural Sector Policy 2007–2012 was developed in draft form in mid-2007. While considered a sound policy for supporting development of agricultural production and trade, it was not specific in its analysis of the key issues facing the sector. Indeed, the policy never went beyond draft form, and was never publicly released. This is despite the fact that the Vanuatu Government's Priorities and Action Agenda 2006–2015 emphasised primary sector development as a key national priority area (Ministry of Finance and Economic Management 2006).

Finally, the Vanuatu Agriculture Sector Policy 2015–2030 was adopted. This policy, developed under the auspices of the Ministry of Agriculture, Livestock, Forestry, Fisheries, and Biosecurity (MALFFB), expands upon the principles set out in the Productive Sector Policy, which was a broad-sector policy. The 2015 Agriculture Policy goes some way towards promoting agroforestry. With the aim of achieving environmental sustainability, it seeks to assimilate agroforestry considerations and technologies with agricultural production, together with the incorporation of organic farming practices (Ministry of Agriculture, Livestock, Forestry, Fisheries, and Biosecurity 2015). The policy is brief, however, in terms of details of implementation. While the policy encourages incorporating agroforestry as a sustainable farming practice, a major oversight is the failure to guide the roles of the different government departments, particularly cooperation between the Department of Agriculture and Rural Development and other relevant departments including livestock and forestry.

AGROFORESTRY AND RELEVANT GOVERNMENT DEPARTMENTS OF VANUATU

The Ministry of Agriculture, Quarantine, Forestry and Fisheries (MAQFF) is responsible for policy formulation and implementation in the agriculture sector, overseeing both the Department of Agriculture and Rural Development and the Department of Forestry. Responsibilities of the Department of Forestry include administration of the Forestry Act; enforcement of the Code of Logging Practice 1998; integration of climate change issues into forestry planning and projects for sustainable forest management, as outlined in the NAPA (National Advisory Committee on Climate Change 2006); and implementation of both the Vanuatu Forest Policy 2013–2013 and Vanuatu's national REDD+ program.

The Department of Environment and Conservation, established in 1986, is tasked with the conservation, protection and management of Vanuatu's natural resources. The Islands Council of Chiefs, established under the National Council of Chiefs Act 2006, is also tasked with promoting sustainable social and economic development. This includes the formulation and implementation of environmental policies to ensure ecologically sustainable development in Vanuatu. To date, however, no such policies have been formulated. Instead, Vanuatu's REDD+ program and policy were formulated in response to forestry concerns and emerging issues in relation to climate change.

The government has expressed an aim to reduce inconsistencies and duplication in climate change projects and programs by promoting joint governance of climate change with disaster risk reduction. From 2012, this direction has seen the National Advisory Committee on Climate Change merge with the agency responsible for disaster risk management into one advisory body: the National Advisory Board on Climate Change and Disaster Risk Reduction (NAB). Accordingly, the NAB will oversee coordination and implementation of both projects prioritised under Vanuatu's 2006 NAPA and action plans specified under the NCCAS. The Meteorological, Geological Hazards and Climate Change Bill is a draft piece of legislation which, when enacted, will provide for the legal mandate, duties and powers of NAB as Vanuatu's supreme policy-making and advisory body for all disaster risk reduction and climate change programs. The Bill is currently the subject of finalisation, having been prioritised to be brought before Parliament for enactment (Ministry of Climate Change Adaptation, Meteorology, Geo-Hazards, Environment, Energy and Disaster Management 2013).

Vanuatu Forest Policy 2013–2023 clearly identifies the Department of Forestry as the leading governmental organisation for developing sustainable agroforestry. However, promoting agroforestry in Vanuatu will likely require cooperation between various government departments. Vanuatu Forest Policy 2013–2023 envisages there being coordination between the Forestry Department and the Departments of Land, Agriculture and Rural Development, and Environmental Protection and Conservation. In reality, there exists a significant lack of support from these non-forestry departments, and until there are joint efforts as such, implementation gaps will persist, with agroforestry remaining a grey area. With respect to agricultural policy for instance, NZAID in 2008 denounced the constraints on agricultural development caused by MAQFF having poor leadership and standards of governance and lacking a clear policy and strategy for the sector (New Zealand Agency for International Development 2008).

CONCLUSIONS

As noted earlier, an enabling legal and policy framework is needed for promotion and sustainable development of agroforestry in Vanuatu. In this regard the following can be undertaken.

- A national agroforestry strategy should be developed for better cooperation between relevant government departments, clearly identifying responsibilities for each department.
- The Vanuatu government should take immediate initiatives for management of agricultural leases, particularly lease to foreigners.
- An effective land-use planning system should be established.
- Creation of an enabling legal and policy framework for agro-based industry is needed.
- Agroforestry should be recognised as a specialised sector in future agricultural legislation.

In some countries a legal framework has been developed for managing and promoting community or social agroforestry development in partnership with government and farmers' groups. Vanuatu could explore this option through a feasibility study to encourage indigenous landowning units to undertake community agroforestry projects on a public–private partnership basis.

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14. Agroforestry and sustainable livelihoods in Fiji: two case studies

Mohammad Alauddin, Md Jahangir Kabir and Md Saiful Karim

Abstract

This paper reports two case studies on agriculture and agroforestry systems in two contrasting farming settlements on the island of Viti Levu, Fiji. The settlements differ in terms of cropping systems and land tenure regimes. In one settlement farmers' livelihoods are based on diversified cropping systems including agroforestry, while in the other farmers have sugarcane-based farming systems. One settlement is characterised by secure property rights while the other has less secure property rights. Common problems facing both villages relate to access to markets and improved technology, obtaining fair prices for agricultural produce, high transportation cost, vulnerability to natural disasters, and poor access to credit and research and extension services. Problems specific to the sugarcane-based farming systems relate to land tenure insecurity, non-availability of farm workers during harvesting season and lack of labour-saving technology. It is argued that support is needed for the farming communities in terms of ensuring easier access to product markets and storage, access to improved technology including mechanisation, creating a more secure land tenure regime, increased research and extension services, and affordable transportation services. The policy response may involve consolidation of holdings so that bigger farms can employ mechanical technology more efficiently for sugarcane cultivation. Smaller farmers currently growing sugarcane require support to diversify their farming activities and grow other crops such as vegetables, fruit and staples.

LAND TYPES AND LAND-USE PATTERNS IN FIJI

Land management and land-use rights are major issues in the promotion of agroforestry in Fiji. The total land area of Fiji is about 18,300 km². The iTaukei Land Trust Board is entrusted with the management of 88% of the national land area which is owned by the indigenous Fijian people; of the remainder, 4% is owned by the state and 8% is freehold land (Sue 2010, p. 5).

Land in Fiji is classified based on its suitability for agriculture. Land which is suitable for cropping without any modification is considered Category I or first class land. This category occupies about 355,900 ha or about 19.4% of the total land area of Fiji. Category II is suitable for agriculture but minor modification is needed; about 193,280 ha are this category, or 10.5% of the land area of Fiji. Together these two categories of land cover almost 30% of the total land area, and little or no modification is needed before it can be developed fully for some form of agricultural use (UNCCD National Focal Point 2007, p. 11).

Agricultural land in Fiji is used primarily for cultivating temporary and permanent crops, pasture and coconuts, or is occupied by natural or planted forest. The highest percentage of arable land is used for permanent crops (31%) followed by pasture (19%) and natural forest (17%) (NACR 2009, p. 19). Of the total area, 43% (7,900 km²) is available for tree crops and grazing and only 16% (2,900 km²) of the total land is arable land (Sue 2010, p. 8). The area of arable land and tree crops other than coconuts is only about 1,950 km² together with planted mahogany and Caribbean pine (1,000 km²) (FAO 2009, p. 6).

Due mainly to increased population, pressure on the land and particularly on marginal land has increased, resulting in land degradation. Relatively flat land is mainly used for commercial cropping (e.g. sugar, ginger, kava and taro) and grazing cattle, while the cultivation of perennial fruit and nut trees and subsistence crops (root crops, pulses and rice) for increasing income and self-reliance has been intensified on the steeper slopes. Shortening fallow periods and ceasing the traditional mulching practice has also accelerated soil erosion. In addition, without adopting soil conservation measures, expansion of sugarcane onto slopes greater than 11° causes soil depletion and moisture deficits, resulting in reduced sugarcane yield (UNCCD National Focal Point 2007, pp. 29–30).

AGRICULTURE AND AGROFORESTRY IN FIJI

Three-fifths of the Fiji land area (10,850 km^2) is occupied by natural forest. Fiji has a suitable environment for producing a wide variety of tropical fruit and vegetables. Agricultural growth is necessary for local consumption by Fijians and tourists, as well as export of high-value commodities and niche agricultural produce. Although the contribution of agriculture to the national GDP has decreased to about 8.2% annually from about 15% in the mid-1990s, agriculture is still the mainstay of the economy and generates around 28% of employment in the formal sector as well as indirectly employing many more (DoA 2013, pp. 18–31).

The sugar industry, non-sugar commercial crops and subsistence cropping are the three types of agriculture in Fiji. The sugar industry has stabilised despite reduced prices in the EU market, and expiry of land leases for sugar. Non-sugar commercial agriculture is mainly confined to horticultural crops, particularly for export. Fruits, vegetables and root crops (notably taro, cassava and sweetpotato) are the main export crops. Coconuts and fruit products and nutraceuticals are exported on a relatively small scale and growth of the sector is highly volatile (DoA 2013). In fact, the traditional commodities of sugar and copra are struggling but horticultural crops are achieving greater success in export earnings. Nearly 33% of households are subsistence farmers, cultivating traditional fruits, vegetables and root crops for consumption and livelihoods (DoA 2013, pp. 18–31).

Sugar, kava, taro, rice, ginger, eggplant, cassava and tropical fruits are major crops in Fiji. Ginger is a non-traditional crop but is an important diversification crop that generates domestic income, export earnings and employment for farming households.

Intercropping trees with the dominant staple food crops in home gardens and around villages in upland and alluvial lowland areas and river terraces is a widely practised agroforestry system in Fiji. The fallow period generally ranges from 5 to 15 years while cropping periods range from 2 to 7 years. However, the cropping period is usually longer and fallow period shorter in the vicinity of the villages. The fallow period is decreasing partly due to increased demand for food and partly due to availability of short turnaround crops such as cassava which can be grown in three successive crops within a year.

The productivity and profitability of rain-fed farming in Fiji has been affected by natural disasters, variability of prices, poor access to markets and increasing transportation costs, pest infestation, diseases and theft (NACR 2009, p. 21).

THE CASE STUDIES

The case studies focus on two contrasting farming settlements on Viti Levu, namely Narau (near Rakiraki) and Tunalia (near Nadi). The settlements differ with respect to cropping systems and land tenure regimes. One settlement has its livelihoods based on diversified cropping systems including agroforestry, while the other practises sugarcane-based farming. One settlement is characterised by secure property rights while the other has less secure property rights. The case studies examined farming practices, changes that have taken place over time, access to land, markets and technology, and constraints that the farmers face in sustaining their livelihoods in the two settlements.

Discussion with Sugar Research Institute Fiji (SRIF) Acting Chief Executive at the SRIF headquarters at Lautoka and scientists at the research station near the Narau farming settlement provided useful insights to the farming systems. All meetings and discussions took place between 10 and 23 May 2015.

Six farmers in Narau and seven farmers in Tunalia were selected as case study households for gathering information on farming and livelihood activities. Data were collected through focus group discussions and farmer interviews. Two focus group discussions were conducted with eight knowledgeable farmers in each village. The first focus group discussion in each village collected data to provide an overview of the farming systems, farming practices, livelihood activities and constraints that affected farm productivity, profitability and livelihood sustainability. The second focus group discussion in each village validated the information previously gathered.

Narau farming settlement, originally in a sugarcane-growing area, was established in its present form about 30 years ago when it was settled by indigenous Fijian communities. Land tenure is typified by community ownership of land with its members having secure rights to land usage. In the current settlement, sugarcane has almost completely been replaced by diversified cropping systems, growing vegetables, fruit and staples in home gardens as well as some field crops. There is significant agroforestry practised. Transportation problems and labour shortage precipitated the change from sugarcane cultivation, although sugarcane growing continues in areas close to the main highway in Narau.

Tunalia farming settlement is inhabited primarily by Indo-Fijian communities. Thirty year leases with the possibility of renewal at their expiry epitomise the land tenure system in this settlement. Farming systems revolve around sugarcane cultivation that represents a way of life in this farming community. Other crops, including vegetables and fruit, are primarily grown in homestead areas for home consumption. Vegetables (including beans, eggplant and cabbage), staples (including cassava and taro) and fruit (including pineapples) are either intercropped or grown as main field crops for commercial purposes. Livestock including beef cattle and poultry as well as aquaculture feature in the farming systems in Tunalia.

From focus group discussions and interviews it was found that the two communities face some common problems, relating to:

- market access;
- the need for improved technology;
- lack of storage facilities for produce;
- obtaining fair prices for their produce;
- high transportation costs;
- natural factors such as droughts;
- water shortage for crop production;
- lack of ready access to credit;
- lack of access to research and extension.

These limit farm productivity and profitability and undermine sustainable livelihoods. The main constraints to agroforestry identified by focus group participants in Narau were their inadequate resource base (lack of land and lack of money), lack of markets, and limited knowledge of managing agroforestry. Participants reported that heavy rain caused soil erosion in areas where there is little tree cover. Prolonged dry and wet spells can reduce crop yield by up to 50%, while insects, diseases, birds and flying foxes cause crop losses of about 30%. Survey participants reported on non-farm employment, government assistance and their traditional methods of coping with these adversities. Lack of markets, oversupply and lack of storage facilities were the main factors that threatened farm profitability. Participants identified access to land, credit, markets, better information and extension services, education and training as key factors for enhancing and sustaining profitability.

Problems specific to the Tulania farming settlement relate to: less secure land tenure; severe shortage of labour, especially during harvest time; and lack of mechanised (labour-saving) farm operations. These problems further erode the economic viability and sustainability of livelihoods of the Tunalia community. These problems also threaten environmental sustainability by degrading the land on which sugarcane is grown because the farmers do not replant their sugarcane crop every five or so years as recommended by the SRIF. This also reduces adoption of new and improved sugarcane varieties and makes sugarcane monoculture more deeply entrenched. The farmers in the sugarcane-growing areas of Tunalia did not support agroforestry to replace sugarcane.

CONCLUSION

The case studies show that reform is needed for a conducive policy environment that includes:

- easier access to resources such as cheaper credit;
- access to new technology at affordable cost;

- stronger R&D and extension services;
- stronger marketing and storage agencies;
- provision of labour-saving technology such as tractors and harvesters on a community basis to reduce the mounting labour cost; and
- reduction in transportation costs for farm produce.

Given that the Fiji sugar industry will soon need to compete in the world market (after the withdrawal of price support by the EU), the only way the sugar industry can survive is to ensure higher productivity and lower production costs. The following policy response may be suggested from these case studies:

- Consolidation of holdings into bigger farms that can employ mechanical technology more effectively and efficiently.
- On smaller farms currently growing sugarcane, support to diversify their farming activities to growing other crops including vegetables, fruit and staples.
- A longer term and more secure land tenure regime to reduce uncertainty regarding farming in the sugarcane-growing areas.

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15. Agroforestry and sustainable livelihoods in Vanuatu: insights from two case studies

Mohammad Alauddin, Md Jahangir Kabir and Md Saiful Karim

Abstract

This paper provides a brief overview of agroforestry systems in Vanuatu through case studies on two villages on Efate Island, Etas and Epau. Epau village is longer settled and is characterised by secure property rights, while Etas is a newly settled village with less secure property rights. Common problems facing both villages relate to access to markets and technology, and lack of storage facilities for agricultural produce. These limit farm productivity and profitability, and undermine sustainable livelihoods in both villages. The findings indicate the need to provide an enabling environment for the farming communities by ensuring easier access to markets and technology. This calls for strengthening the agricultural research and development and extension services and stronger marketing agencies. Livelihoods in the village with less secure property rights appear less sustainable.

INTRODUCTION

Vanuatu is an archipelago of volcanic islands and submarine volcanoes located between latitude 12° and 23° south and longitude 166° to 173° east. There are more than 80 islands, with a total land area of 12,336 km² and a maritime exclusive economic zone of 680,000 km². The two largest islands—Espiritu Santo and Malekula—comprise nearly 50% of the total land mass (NACCC 2005).

Vanuatu is an agrarian country. Nearly 80% of the population live in rural areas and depend on agriculture for their livelihood, with an average farm size of less than 1 ha (VNSO 2007). Copra, cocoa, kava and cattle are the main rural exports and these, along with coconuts, timber and handicrafts, are the major sources of cash for rural households. Agriculture contributes nearly 80% of total household income (VNSO 2007, p. 18). Vanuatu exports mainly agricultural commodities including copra, coconuts, cocoa, beef, veal, kava, cowhides, sawn timber, and live fish and shells. Beef and veal are the major export commodities of the country (VNSO 2007, 2009, 2013). However, commodity export earnings are highly unstable due to price volatility in international markets (VNSO 2009). Fishing, offshore financial services and tourism also support the economy.

Agroforestry plays a role in providing food, cash and employment for communities. Intercropping of food and cash crops with fruit and timber trees in home gardens and village groves is the common agroforestry system in Vanuatu (UNU 1993).

This paper presents two case studies on agroforestry practice in Vanuatu.

AGRICULTURE AND AGROFORESTRY IN VANUATU

Almost 70% of the land area of Vanuatu is under forest, with the non-forested land used primarily for agriculture and residential development (FAO 2008, p. 38). Of the total land area, 9.5% has been leased—for various agricultural, commercial/tourism, industrial, residential and special purposes—of which 82% is leased for agriculture (Sue et al. 2012, pp. 2–5).

The staple foods in order of importance in Vanuatu are yam, taro, banana, rice, cassava, bele or okra (which has edible leaves, flowers, seedpods and mature seeds), sweetpotato, kava, fruit and vegetables. The major farming systems are relay intercropping, mixed systems (cattle under coconuts, cocoa under coconuts), kava monocropping, and agroforestry with food crops planted with diverse trees (APN 2010, p. 21).

Home garden cropping and livestock rearing mainly for home consumption are the major activities of subsistence agriculture, along with fishing and forestry-related activities. Households cultivate vegetables (including cabbages and beans), root crops (including yam, taro, sweetpotato and cassava) and fruits (including mango, grapefruit, coconut and kava) as homegarden crops. Households also rear cattle, pigs, goats and chickens. People living near the coast catch fish, shellfish and crustaceans and some households collect 'bushfoods' from surrounding forest (VNSO 2007, p. 20).

The coconut palm is ubiquitous in the coastal areas, within home gardens and areas under short-term fallow. The following trees are also important sources of food and cash for households: breadfruit, mango, papaya, citrus species, Tahitian chestnut (*Inocarpus fagifer*), Pacific lychee (*Pometia pinnata*), beach almond (*Terminalia catappa*), and Malay or mountain apple (*Syzygium malaccense*). Bananas and plantains (*Musa* spp.) and cocoa planted in both lowland and upland gardens are important cash crops. In the Middle Bush gardens mulberry (*Morus alba*), peach (*Prunus persica*) and *Finschia chloroxantha* (an edible fruit) are found (UNU 1993).

Prices of major cash crops, including cocoa, coffee, copra and kava, vary and fluctuate on the world markets. For example, the price of copra—one of the most important sources of cash income for farming families in Vanuatu—has been declining in real terms for the past two decades. There is a lack of effective extension services for disseminating modern technologies to farmers, e.g. on improved varieties and on livestock feed. Productivity of crops and livestock is low due mainly to lack of knowledge on modern farming practices (DESP 2006, pp. 26–27). The challenge is to increase farm productivity and output, and improve marketing systems and market access for both traditional food crops and high-value specialty commodities. The major bottleneck for agriculture is that the productivity of traditional crops is low and marketing is difficult because of poor inter-island and intra-island transport services (DESP 2006, p. 25).

There is a major opportunity for expansion of high-value crops and livestock in Vanuatu due to the favourable climate. This includes the potential for producing organically grown food products and cash crops including cocoa, coffee and kava (DESP 2006, p. 27).

THE STUDY VILLAGES

Case studies were undertaken in Etas and Epau villages on Efate Island to investigate farming practices, changes that have taken place over time, access to land, markets and technology, and the constraints that farmers face in sustaining their livelihoods. The fieldwork was undertaken between 25 February and 4 March 2015. Data were collected from two focus group discussions with four or five knowledgeable farmers in each village. The first focus group discussion in each village collected data to provide an overview of the farming systems and the issues above. A subsequent focus group discussion in each village validated the information. In addition, four farmers in Etas and five farmers in Epau were selected as case study households for eliciting in-depth data on farming and livelihood activities.

Etas is a newly settled area in the southwest of Efate, about 8 km from Port Vila. One of the landowners subdivided his land into 27 plots and sold these separately under separate land titles. Twenty-six plots were sold and the largest plot of 5 ha was retained by the landowner. The sold plots have area between 1,000 and 2,000 m^2.

Etas has a population of about 100 people in 27 households. The major agricultural activity in this area is subsistence farming while one farm is commercial. Families grow fruit, coconuts, yam, vegetables, spices, bananas, cabbages, peanuts, watermelons and cucumbers. One household has a coconut plantation with less than 100 palms, and sells the nuts in the local market. The villagers carry out agricultural practices manually using traditional tools including knives, spades and sticks. Only one farmer—the farmer who owns the 5 ha area of land—practices agroforestry, using a tractor to cultivate the land. There is no use of chemical fertilisers. With no irrigation facility, farmers depend on rain. There is no evidence of wage-based employment on the farms. Families do their own work with occasional assistance from extended families or other community members.

Many of the people living in Etas village work in Port Vila. Some are interested in carrying out larger scale farming, but are prevented by limited land availability. Currently, only one household is a non-farming household. Most households raise chickens on a non-commercial basis; only one household is raising pigs.

The other study village—Epau—is located about 60 km north of Port Vila and has a population of 500–600 people in 50 families in a long-established village. Agriculture in the village evolved in several phases. In the 1980s there was little agriculture, and livelihoods were dependent on cattle rearing and hunting and gathering from the wild. By the late 1980s, a logging company had removed almost all the timber trees with no replanting carried out. In the 1990s the present agriculture and agroforestry started to emerge. Crops included fruit (including orange, mandarin, banana and pineapple), root crops (especially sweetpotato, yam and taro) and vegetables (including Chinese cabbage, island cabbage and cucumber). Forestry included plantations of whitewood, mahogany, kauri and natapoa.

At the beginning of the 2000s, there was an increasing trend towards growing sandalwood and nangai (*Canarium indicum*). Crops are intercropped with timber trees, and fruit trees typically surround the houses. There are a few timber trees on each homestead block, with sandalwood as the only non-fruit tree on some blocks. Crops include yam, taro, cassava, sugarcane, citrus, nangai, mango, coconut, navel or cutnut (*Barringtonia edulis*), naus (*Spondias dulcis*), breadfruit, wild nandau (*Pometia pinnata*), nakatambol (*Dracontomelon vitiense*) and namambe (*Inocarpus fagifer*). These crops collectively represent a 40:60 ratio of home consumption and market sales. On average 90% of the fruit harvested is sent to the market. Over the last 10 years, every year the villagers clear and bring new land under cultivation, in a form of slash and burn agriculture.

The households enjoy customary rights to the land. They secure the right to access the land in exchange for one day per week labour to the local chief. This gives the villagers enough land for their livelihoods, and only 1% of the villagers engage in non-farm activities. Recently, the villagers have had an opportunity to engage in community-based agroforestry with the availability of new and more productive varieties.

CASE STUDY FINDINGS

Etas village

The most common non-fruit tree is sandalwood, which every case study household has planted. The average number of sandalwood trees per household is 10 with an average tree age of 4 years. This is high-value tree crop harvestable at an age of 20 or more years.

Table 1 presents a summary of the fruit trees on the land of the four case study farmers. One household has 14 coconut trees of which 10 are fruit bearing. Coconuts are grown primarily for market with any unsold used for home consumption. As for other fruit species, most trees are about three years old while the fruit-bearing age is 5 or more years.

Figure 1 illustrates the proportion of commercial versus subsistence use of the major crops grown by the case study households. Sweetpotato, yam, taro and choko are primarily for home consumption (more than 80%) while sugarcane, cassava, banana, cucumber and namambe have greater commercial orientation (more than 60% marketed). Among the minor crops (illustrated in Figure 2), corn, watermelon

Table 1. Fruit trees grown in case study home gardens in Etas village.

Fruit tree species	Average no. of trees per household
Mango	4
Orange	3
Breadfruit	1
Mandarin	1
Avocado	1
Naus	1
Namambe	1
Grapefruit	1

and pineapple are primarily for home consumption (more than 80%) while peanuts, tomatoes, Chinese cabbage and island cabbage are primarily destined for the market (≥ 80%).

Farmers sell their produce in the local market 6 km away. Occasionally, they may be sold in the downtown market, which is about 15 km from the village. Quantities sold and prices vary widely depending on the weather. Yield in a poor year can be as low a third to a quarter that in a normal year, while prices can fall to 50% of the average price.

Epau village

Figure 3 shows the average number of fruit and non-fruit trees per household in Epau village. The most common timber tree species is whitewood followed by

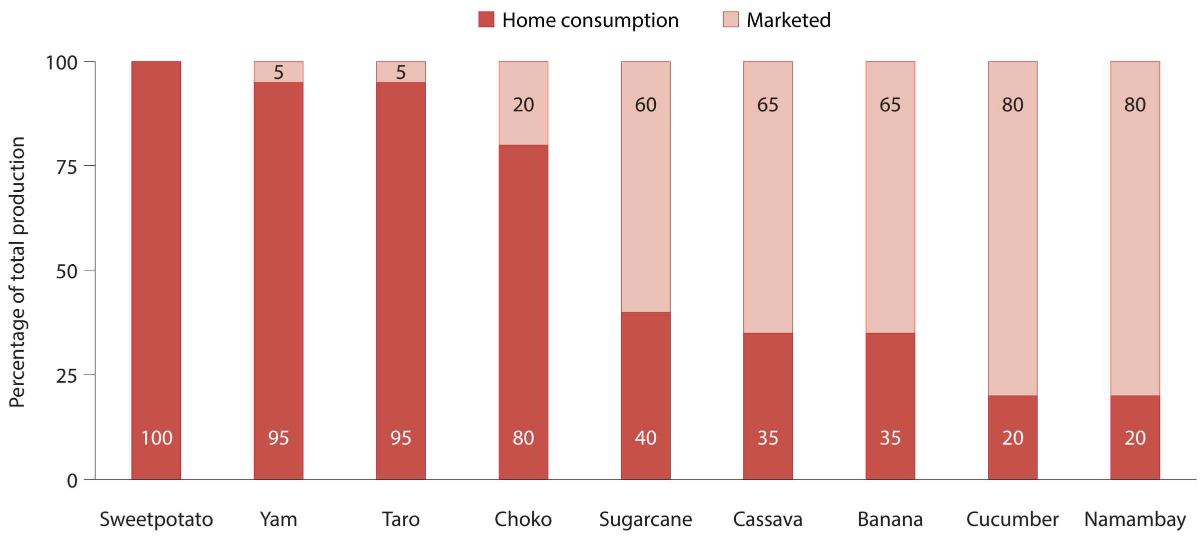

Figure 1. Major crops cultivated in Etas village, and their commercial versus subsistence use.

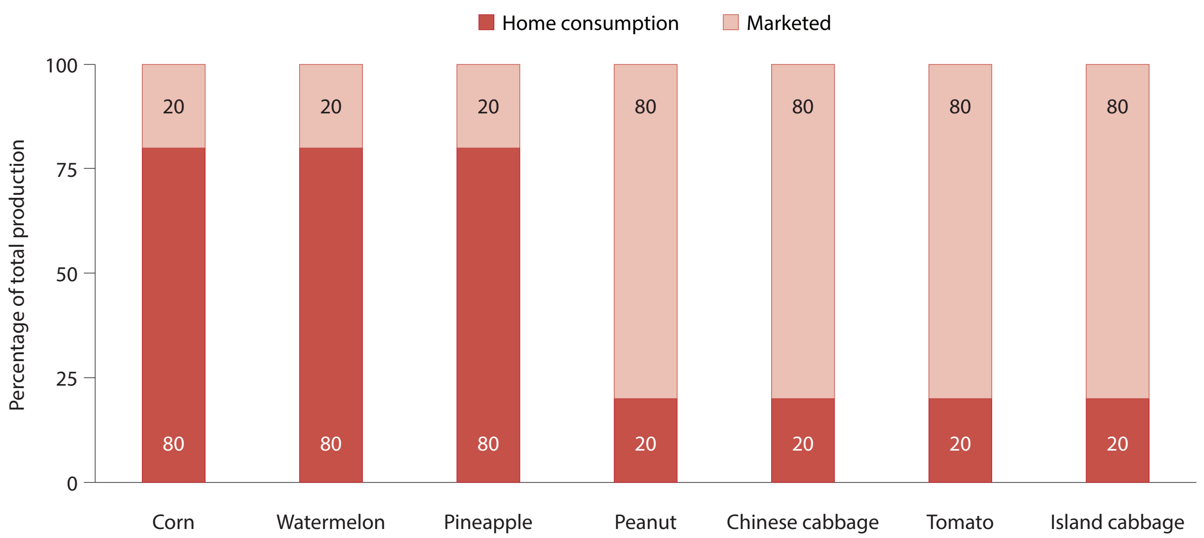

Figure 2. Minor crops cultivated in Etas village, and their commercial versus subsistence use.

sandalwood, nangai and mahogany, while coconut is the most important fruit crop.

Figure 4 shows commercial crops grown in the village. Coffee is the most commercially oriented crop with zero home consumption, followed closely by coconuts and oranges with 5% home consumption, while papaw and nakafika have the least commercial orientation with 40% home consumption. Other crops with an intermediate level of home consumption are nafel (10%), naus (10%) and grapefruit (35%).

Of the major non-fruit food crops produced in Epau village, island cabbage and yam are the most commercially orientated crops, with over 90% sold in the market. The other two important crops in this category are taro and cassava, each with 80% sold commercially.

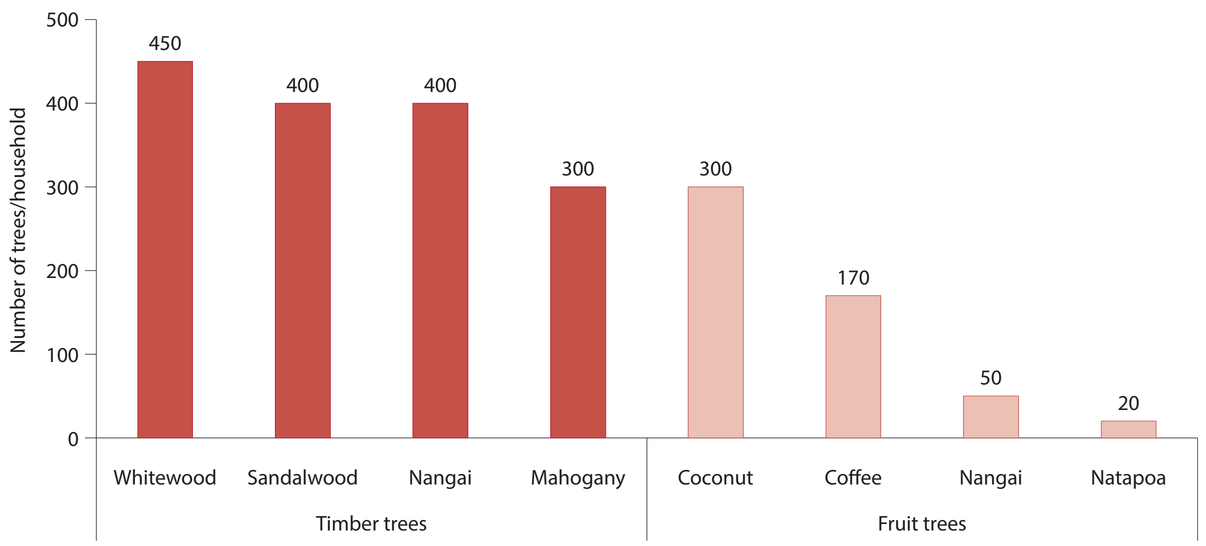

Figure 3. Commercially cultivated trees in Epau village.

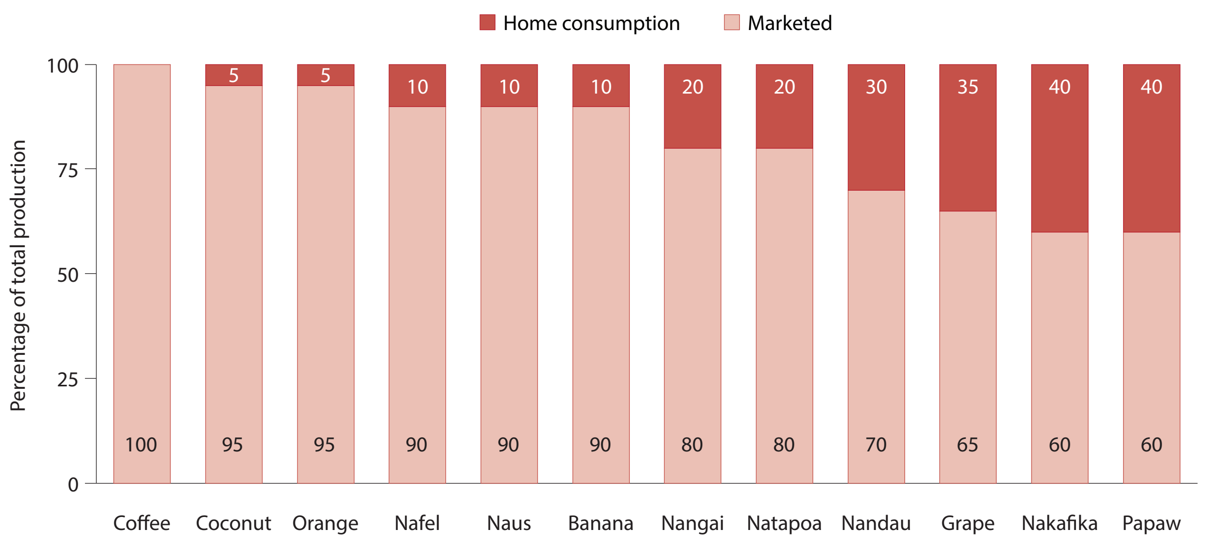

Figure 4. Commercially oriented major fruit crops cultivated in Epau village.

Table 2 lists major and minor fruit tree species grown in Epau. Among the non-fruit trees grown in home gardens sandalwood is the most prominent and is grown by every case study household. Table 3 lists major and minor field crop species intercropped with timber plantations.

The main constraints to agroforestry identified by the participants in both the villages are a lack of financial resources, lack of markets, and a long wait for financial returns. Participants identified access to credit and markets, better information and extension services, and improved education and training as key factors in enhancing and sustaining profitability. Etas village participants also identified lack of land availability as a major constraint to agroforestry.

Table 2. Major and minor fruit trees grown in homesteads in Epau.

Major fruit tree species	Minor fruit tree species
Orange	Mango
Nafel	Mandarin
Naus	Lime
Nandau	Breadfruit
Nakafika	Mandarin
Grape	Nakatambul
Pawpaw	Lime

Table 3. Major and minor field crops intercropped in timber plantations in Epau.

Major field crops	Minor field crops
Banana	Chinese cabbage
Island cabbage	Spring onion
Cassava	Sweetpotato
Yam	Cucumber
Taro	Tomato
	Lettuce
	Capsicum
	Beans
	Pineapples

CONCLUSION AND POLICY IMPLICATIONS

Case studies on the two villages of Etas and Epau on Efate Island reveal major differences with regard to land use. Epau is longer established and is characterised by secure property rights. Households in this village are much better endowed with land resources and have greater capability to cope with adversities than those in Etas, which is newly settled with far less secure property rights and poorer endowment of land resources. Common problems facing both villages relate to access to markets and technology and lack of storage facilities. These limit farm productivity and profitability and undermine sustainable livelihoods in both villages. Etas village with less secure property rights appears less suitable for promoting agroforestry because of risk in long-term investment.

Policy implications are that there is a need for a more enabling environment for the farming communities by ensuring easier access to markets and technologies and creating more secure property rights. This calls for strengthening the agricultural R&D and extension services and stronger marketing agencies. However, poorly resourced Etas villagers may not be able to sustain their livelihoods based entirely on farming, and non-farm employment opportunities may be needed. The geographical proximity of Etas to Port Vila could provide some advantage in creating such non-farm employment opportunities.

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