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Financial Modelling of Mixed-species Agroforestry Systems in Fiji and Vanuatu, Based on Traditional Tree Species

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ABSTRACT

Multi-species agroforestry has a long history in the Pacific Islands, and many benefits of this practice have been identified. The area of agroforestry declined in these countries during the colonial era and, although there has been renewed interest over the last 30 years, only a small area has been planted. Many tree species with high-value timber and other products are indigenous to the Pacific Islands, but there has been little experience of growing most of these in plantations. In a research project funded by the Australian Centre for International Agricultural Research (ACIAR), a component was included on developing financial models of multi-species agroforestry systems including 'novel' tree species, in Fiji and Vanuatu. This involved developing a suite of financial models for individual tree and crop species, identifying suitable planting sites and compatible mixtures with financial and environmental potential, and then integrating these multi-species models in Excel workbooks. This paper discusses choice of financial analysis method, identifying priority multi-species mixtures for Fiji and Vanuatu, and performing financial analysis. Financial performance estimates are reported for a number of agroforestry systems judged suitable for particular site conditions. Comments are made about the strengths and weaknesses of the analysis approach, and policy implications of the study, and suggestions are made for further research.

Keywords: Multi-species agroforestry, intercropping, species-site matching, wildfire

INTRODUCTION

Agroforestry has been a widely practiced landuse in Fiji and Vanuatu. Thaman et al. (2000, p. 27) 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, from the first human settlement 1000 or more years ago, through 'colonial agrodeforestation' during the 19th and 20th century (when colonial governments promoted 'monocultural export cropping and livestock grazing' of coconuts, cocoa, sugarcane, and other crops), then *Post-World War 2 agroforestry* of growing cash crops and unsustainable logging, with discouragement of traditional agroforestry practices accompanied by increasing rates of 'nutritional disorders', to late *21st century agroforestry re-enrichment* when there was 'active promotion of MSA' or mixed-species agroforestry.

A potential impediment to agroforestry development in Fiji is that – unlike agriculture and forestry which have particular departments in government responsible for their activities – no single department is the champion for agroforestry, which 'falls through the cracks' in terms in terms of administrative support. Clearly, the Fiji Department of Forestry (within the Ministry of Fisheries and Forests) and Department of Agriculture (within the Ministry of Agriculture, Rural and Maritime Development and National Disaster Management) have responsibility over various facets of agroforestry. But so would the Ministry of Lands and Mineral Resources (including the Department of Lands and Surveys which is responsible for the administration of all development on State Land in Fiji), Ministry of Local Government, Housing, Environment, Infrastructure and Transport (in which the Department of Local Government oversees activities of Fiji's 12 municipal local governments), and Ministry of Industry and Trade and Tourism. As well, the iTaukei Land Trust Board (TLTB), formerly known as the Native Land Trust Board, has a major stake and influence in land use. In Vanuatu also, there is no single authority to champion agroforestry.

Agroforestry development is seen to have many attractive features in Pacific Island countries, including promotion of agricultural development, reduction in land degradation, import replacement, and improved community health. The ACIAR project ADP/2014/013 – *Promoting sustainable agriculture and agroforestry to replace unproductive land-use in Fiji and Vanuatu* – was undertaken to examine financial, social, environmental and policy aspects of agricultural and agroforestry development in areas of declining sugar production and senile coconut plantations in Fiji and Vanuatu. The focus was on using Pacific Island tree species not generally used in industrial forestry (including timber, fruit and nut species) together with food crops. A series of 12 unpublished working papers has been prepared in the ACIAR project, by the authors and with contributions from others in the project, relating the land use and agroforestry in the study area, from which this paper draws extensively.

Recent pronouncements on agricultural policy in Fiji favour modernization and a larger scale of production, which does not necessarily favour agroforestry. The report Fiji 2020 on modernizing agriculture (Fiji Ministry of Agriculture, 2014), stresses that 'The country's pace of transformation from subsistence to commercial scale agriculture is still slow' (p. 7) and that 'the twin goals of import substitution and food security remain elusive (pp. 14-15). However, reference is made to 'agroforestry in the upland areas where the forestry and agriculture sectors converge', through adaption of 'Sloping Agriculture Land Technology (SALT) and the Line Planting Technology' (p.2). The former is referred to as 'a form of alley farming in which field and perennial crops are grown in bands 4-5 m wide between contoured rows of leguminous trees and shrubs. The latter is envisaged as commercial trees and agriculture crops where the trees are planted at close spacing in rows in an east-west direction to maximize sunlight entering alleys in which 'Root crops, legumes, sweet sorghum, and other biofuels crops are used as the intercrop'.

Some parallels and differences may be drawn between designs of mixed-species plantation systems that were adopted for rainforest cabinet timbers in tropical north Queensland and MSA systems for Fiji and Vanuatu. Carrying out financial analysis of *novel* or *rarely-planted indigenous tree species* faces difficulties in understanding and modelling silviculture requirements, obtaining yield and stumpage price data, and model refinement and validation. However, the challenge becomes even more difficult when modelling mixtures of timber, fruit and nut tree species, and the various short-rotation and annual food and other species which can be intercropped with them. As well, it has been recognized 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 noted by Wikipedia (2015), 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 utilized by a single crop'.

Questions arise as to what species for landholders to grow (and for government to promote) in new agroforestry plantings, referred to by Thamen and Clark (1993) as *institutional* agroforestry systems as distinct from *traditional* systems which often contain small numbers of many species suiting individual household food needs. One component of this research is to determine the likely financial performance of proposed new agroforestry plantings which, together with social, environmental and institutional impacts, can guide choice of species mixtures. Financial analysis can also help guide the choice of measures which could be adopted to encourage such plantings and levels of financial support which may be required.

Various forms of agroforestry have been identified in the Pacific Islands, categorized 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, p. 2-3). In this paper the primary focus is on intercropping, i.e. *multi-species* (or *mixed species*) agroforestry, MSA. Wikipedia (2015) 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).

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

CHOICE OF FINANCIAL MODELLING APPROACH FOR AGROFORESTRY SYSTEMS

A number of approaches have been adopted for financial analyses of MSA systems. Ellis et al. (2004) reviewed various 1990s computer-based decision-support tools used in agroforestry, including databases, geographical information systems, computer-based models, mathematical computer models, knowledge-based or expert systems, and hybrid systems. Four examples reported by Ellis et al. are: *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 in 1991; *BEAM (Bio-economic Agroforestry Model)* – a bioeconomic model to assess physical and financial performance of agroforestry systems, developed at the University of Wales; *AEM (Agroforestry Estate Model)* – an economic model to evaluate agroforestry in combination with other farm activities, developed by Middlemiss and Knowles in New Zealand in 1996; and *AME* (*Agroforestry Modelling Environment*) – an object-oriented modelling tool to graphically visualize, construct, integrate and exchange agroforestry models, developed by Muetzelfeldt and Taylor in 1997. AME has apparently now been developed into the SIMILE simulation package designed for building general ecology models.

In another classification system, 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 optimization models; linear and non-linear programming models; non-market valuation models (e.g. hedonic price and contingent valuation methods); and regional economic models.

Several financial models have been developed for multi-species plantings of lesser-known tropical rainforest tree species. Herbohn et al. (1998) reported the development of a forestry financial model (the Australian Cabinet Timber Financial Model, ACTFM) to predict potential returns from small-scale plantations of high-value rainforest cabinet timbers for which there was little experience of plantation commercial production. A detailed description of the model is provided in Dayanandra (2002, Ch. 13). The ACTFM consisted on 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 NPV, LEV and IRR criteria) – for a woodlot containing up to a five tree species. Default yield, price and other parameter data were provided, which could be overwritten by the user. Estimates of pessimistic, best guess and optimistic growth rates (mean annual increments, MAIs) and stumpage prices were obtained for 32 species with potential for plantation use, through a Delphi survey of forestry experts. Harrison et al. (2001) used the ACTFM with the @RISK software 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, and Visual Basic was adopted instead. 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 an undergraduate student class. 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.

In summary, financial of economic analysis of agroforestry systems, which may include identification of optimal agroforestry systems in terms of the species components, has been performed using a wide variety of software. For this study, a decision was made to use a Microsoft Excel spreadsheeting approach for modelling agroforestry systems in Fiji and Vanuatu because this software is well known to researchers and the community in general, has extensive modelling features, and is relatively easy to use. Excel contains a wide variety of financial functions to aid discounted cash flow analysis, including those needed for calculating financial performance criteria and also for sensitivity analysis, breakeven analysis and scenario analysis. The ability to trace precedents and dependents assists in checking formulae. The ability to combine spreadsheets in the one Excel workbook creates the opportunity for a modular approach to developing MSA models.

STUDY AREA AND RESEARCH METHOD

The study areas as suggested for the research by ACIAR were the sugarcane growing areas in the Western Division in Viti Levu in Fiji and Efate Island in Vanuatu. In the former the sugar industry, though still important to the Fiji economy, has contracted with declining sugar prices. In the latter, due to a decline in international copra prices, some of the coconut plantations are aged and have reduced yields, and opportunity exists for intercropping or replacing these plantations.

Applying financial analyses to potential mixed-species agroforestry plantations based on traditional tree species presents major challenges in terms of data collection and of model formulation and validation. The approach adopted has been to collect data from field visits and limited surveys under ACIAR project ADP/2014/013, and literature search, to initially model individual species, and then to adapt and integrate the single-species models into agroforestry systems models. A number of research steps were required:

1. Identify priority tree and crop species for Fiji and Vanuatu;

2. Compile information on site requirements, for example in terms of land type, climate, shading requirements and shade tolerance;

3. Develop a suite of financial models for individual tree and crop species, for use as modules in MSA models;

4. Choose promising mixed-species agroforestry systems; and

5. Develop financial models for selected MSA systems and compare their financial performance.

RESULTS

The results are reported in the sequence listed in the research method section.

1. Priority tree and crop species for Fiji and Vanuatu

Many lists have been developed for priority species for both Fiji and Vanuatu over the last 20 years, based on various criteria, including the need for conservation of genetic material, the proven performance of the species growing naturally, as sources of timber and other products, international or domestic marketability of the timber and other products, potential for genetic improvement, potential for value-adding of products, suitability for growing in mixed-species agroforestry systems, and traditional values of the species to particular Pacific Island communities. Among the most recent recommendations, Padolina and Kete (2014) of the Secretariat of the Pacific Communities (SPC) identified priority tree and crop species for agroforestry for Pacific Island Countries (PICs) as in the following table (Table 1).

Table 1. Recently listed tree and crop species for mixed-species agroforestry in Fiji

Timber and tree species	Tree species for essential oil
Teak (*Tectona grandis*)	Sandalwood (*Santalum spp.*)
Poloumi (*Flueggea flexosa*)	Coconut (*Cocus nucifera*)
Caribbean pine (*Pinus carribaea)*	Dilo (*Calophyllum inophylpum*)
Mahogany (*Swietenia macrophylla*)	Mokosoi (*Cananga odorata*)
Tropical almond (*Terminalia cattappa*)	Agarwood (*Aquilaria spp.*)
Pandanus spp.	
Trees that provide food, fruit and nuts	**Multipurpose trees**
Coconut (*Cocus nucifera*)	*Grilicidia sepieum*
Breadfruit(*Artocarpus altilis*)	*Azadirachta indica*
Coffee (*Coffea arabica*)	*Moringa oleifera*
Cocoa (*Theobroma cacao*)	*Moringa citrifoia*
Ngale or canarium nut (*Canarium indicum*)	
Mango (*Mangifera indica*)	
Avocado (*Persia americana*)	
Papaya (*Carica papaya*)	
Citrus spp.	

A list of about 60 priority tree species of the Fiji Department of Forestry was made available to the authors, which is notable for including some species not traditionally found in Fiji, including Australian eucalypts. Republic of Vanuatu (2014) noted that 'Five tree species have been selected as priority species for reforestation. These are the sandalwood *(Santalum austrocaledonicum)*, mahogany (*Swietenia macrophylla)*, namamau or flueggea (*Flueggea flexuosa*), whitewood *(Endospermum medullosum)*, and nangai (*Canarium spp.*)'. With the possible exception of mahogany, these species have been recommended for agroforestry systems. In both Fiji and Vanuatu, important food crops sometimes grown together with tree species include citrus, root crops (notably cassava, taro and kumera) and kava, and various vegetable species.

2. Site conditions and species-site matching

A characteristic of many islands in the Pacific region, including Viti Levu which is the most populous island in Fiji, is that eastern areas have high rainfall and western rainshadow areas have lower rainfall and a relatively dry summer, limiting the range of tree and crop species which can be grown. In Efate Island in Vanuatu, the climate is less restrictive.

Government land-use planning in general prescribes that the type of land to be used for agroforestry is not prime agricultural land where agroforestry would not be the 'highest and best' use. Biological constraints restrict planting on low quality land to the more site-tolerant forestry species (such as Caribbean pine or eucalypts). Fiji has adopted a Land Use Capability Classification System based on seven sets of information, relating to geology, soils, relief, erosion, vegetation, land use and climate (Department of Agriculture, nd, p. 7). Eight land capability classes are defined, classes I to III being suitable for intensive agriculture, IV to VII being unsuitable for ploughing but suitable for less intensive cropping under traditional cultivation methods (and hence potentially suitable for agroforestry), and class VII is regarded as unsuitable for productive vegetation.

In the Western Division of Viti Levu, the dry winter months limit the choice of species for agroforestry systems. Tree species suitable for this area include sandalwood, vesi, mango, teak and Caribbean pine, and the food crops of pineapples, cassava, upland taro, and possibly kava. More northerly areas of the Western Division have a more favourable climate, and a wider range of crops can be grown, particularly in lowland and relatively flat areas. Particular requirements of some species were identified, including a need for early shading (e.g. canarium nut), a need for a dry period in the year to flower and hence produce fruit (mango), a need for protection from strong wind (many species), protection from fire (most species), and a requirement for a host species for survival (sandalwood).

3. The financial models for individual species

Data from various sources, including research visits to Fiji and Vanuatu, discussions with ACIAR project in-country collaborators in the SPC and web searches were used in development of a number of financial models, as modules for use in overall MSA system models. These were initially developed for the 10 tree species of breadfruit (*Artocarpus altilis*), canarium nut (*Canarium indicum*), cacao (*Theobroma cacao*), poumuli (*Flueggea flexuosa*), Pacific kauri (*Agathis macrophylla*), sandalwood (*Santalum austrocaledonicum* and *S. yasi*), Tahitian or Polynesian chestnut (*Inocarpus fagifer*), tropical almond or sea almond (*Terminalia cappata*), whitewood (*Endospermum medullosum*) and vesi_or merbau and kwila (*Intsia bijuga*), as well as for the annuals taro or dalo (*Colocasia esculenta*) and velvet bean (*Mucuna pruriens*) as a green manure crop.

In that development of new financial models was found to be highly time consuming, and recent gross margins budgets developed by Leslie (2013) were discovered, the gross margins for additional trees and crops were adapted to generate financial models for use in MSA models. The setting of the GM analyses is as income-earning opportunities for farming on land from which sugarcane production has ceased, in western Viti Levu, Fiji. The coverage is in fact food crops, including fruit trees, and some of the models were for multi-year species and were in effect a hybrid between gross margins and multi-year budgets. Adaption included inflating prices to mid-2015, adjusting labour costs, and adjustments in cash flow timing to the beginning and end of the year. In this way, financial models were developed for nine multi-year species, viz. avocado (*Persea americana*), kava (Yoona) (*Piper methysticum*), mango (*Mangifera indica*), Papaya (*Carica papaya*), Pigeon pea (*Cajanus cajan*), Pineapple (*Ananas comosus*), plantain (*Musa balbisiana*) and sweet orange (*Citrifolia sinensis*), as well as three annuals, viz. dryland taro (tannia, dalo-nitans) (*Xanthosoma saggitifolium*), sweet potato or kumala (*Ipomoea batatas*) and cassava (*Manihot esculenta*).

The financial models take the form of spreadsheets consisting of a number of blocks, setting out the physical and financial parameter values, annual cash flows, financial performance criteria and labour requirements for each tree or crop species. A standard area unit of 1 ha is adopted. The discount rate (weighted average cost of capital) is set at 8%. Yield levels of some tree and crop species – notably fruit and nut species – are specified as schedules of step functions over time.

A major component in the financial models in the labour cost. Work rates for the main silvicultural operations (presented in Table 2) were obtained from consultation with foresters and personal experience of the authors in a forestry joint venture and a silvopastoral system of cattle and macadamia nuts.

Table 2. Work rates for main silvicultural activities

Task	Rate (mins/tree or plant)			
	Timber trees	**Fruit & nut trees**	**Shrubs**	**Root crops**
Land preparation	0	2	2	1
Hole digging and planting	10	15	5	0.5
Fertilizing or mulching at planting	2	2	2	5
Subsequent fertilizing	0	4	3	5
Ring weeding, per round	5	7	5	.01
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			

Other work rates
Site clearing: highly variable depending of site – say 12 hrs/ha
Site fencing, when required – say 16 hrs/ha
Travel to field site and set-up time (incl. tool sharpening) – 10 mins
Field layout: 8 hrs/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 mins/kg
Nut husking: will vary with species – say 6 mins/kg

Wage rates are based on the reported minimum wages in Fiji and Vanuatu for an 8-hour working day, of F$ 18.56 in Fiji and 1400 Vatu in Vanuatu, equivalent to $A 11.50 and A$ 16.80 per day respectively.

4. The mixed-species agroforestry systems selected for financial analysis

Various potentially viable agroforestry systems were identified, drawing on those observed on site visits, suggested by in-country project participants or described or suggested in the literature. Given the time constraints of a one-year project, only five of these species mixtures – labelled agroforestry models AFM1 to AFM5 – were chosen for detailed analysis, as potentially suitable in Fiji, Vanuatu or both. The systems, presented in approximately increasing order of complexity, are:

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

AFM2 – breadfruit (*Artocarpus altilis*) + pineapples (*Ananas comosus*) + cassava (*Manihot esculenta*)

AFM3 – citrus (*Citrifolia sinensis*) + Sandalwood (*Santalum yasi*) + Pigeon Pea (*Cajanus cajan*)

AFM4 – cacao (*Theobroma cacao*) + sandalwood (*Santalum austrocaledonicum* or hybrid) + sweet potato (*Ipomoea batatas*)

AFM5 – canarium nut (*Canarium indicum*) + plantain (*Musa sapientum*) + kava (*Piper methysticum*) + Pacific kauri (*Agathis macrophylla*)

The project life of each agroforestry system is set at the longest harvest age of a timber species, or a more arbitary number of years where a fruit or nut tree has the longest life. Where timber species are included, the analysis extended up to the recommended harvest age of the latest-harvest species, e.g. 20 years for sandalwood and 40 year for Pacific Kauri. To determine the areas of each species in these models, field layout diagrams were drawn, in which the within and between row positions of the longer-term species were first marked, and then the intercrop areas were allocated and their reduction over time as the framework species approached canopy closure were estimated.

5. Development, interpretation and comparison of financial models for each of the five MSA system models

The 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 individual species module. The species modules are adaptions of the financial models described above. Costs which are common across two or more species in an MSA system (shared costs, notably cost of leasing land, land preparation for planting, and tools, equipment and containers for use in harvesting food crops) and costs which are independent of the scale of planting, are treated as overhead costs and moved from the species modules to the summary sheet. Performance criteria in the individual species sheets are limited to the NPV and annual labour requirement, and no sensitivity analysis is provided, the focus of the analysis being on financial performance of the overall agroforestry system, not on individual components of it.

As illustrated in Table 3, the top section 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 (percentage of a hectare) allocated to each species, initial spacing within and between rows, and yield and price parameters. For species for which yield changes over time, *yield factors* rather than discrete values are applied. Yield factors are also used for species where a number of products are sold, notably sandalwood which can produce carving timber, heartwood for oil production, sapwood, fuelwood and edible nuts. This is referred to as a *site and management factor*, and can also be used to reflect the impact of planting site quality. Below these data are sections on common parameters (national minimum wage rate and the discount rate) and on shared costs. These are followed by 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 IRR are calculated.

Critical to performing the financial analysis of MSA is the transfer of data between workbook sheets. As illustrated in Figure 1, data in summary sheets (on areas planted, yields or yield factors, product prices, and the wage and discount rate) are referenced in individual species modules. In turn, the annual net cash flows and labour requirements derived in species modules are referenced by the summary sheets.

Screenshots of components of MSA financial models are presented in Tables 3 - 5. Some of the year columns in the screenshots (mainly those where there is little change in numbers between years) are hidden using the *Column Hide* facility, to ensure that the screenshop detail is not too small for convenient reading.

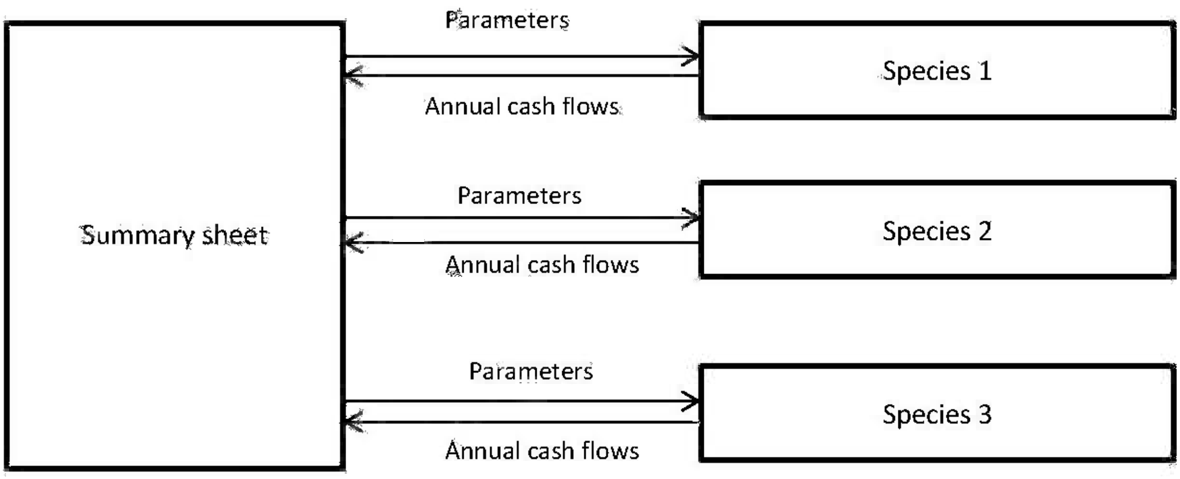

Figure 1. Passing data between the summary spreadsheet and species modules

As indicated in Table 3, mango is grown at a 9 m x 9 m spacing, and about 55% (5/9) of the area is intercropped with cassava for the first five years. The stocking density is 123 stems per hectare of mango and 16,000 plants per hectare for cassava. An aggregate NPV of F$ 122,123 is generated over the 15 year project life. The IRR estimate is not meaningful because the system is designed to minimize early capital outlays, and the small capital outlay leads to an exaggerated return on capital.

Table 3. Example of a summary sheet – the mango and cassava model

	A	B	C	D	E	F	G	H	I
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							

14	Annual net cash flows, mango and cassava											
15	Year	0	1	2	3	4	5	6	7	8	9	15
16	Shared costs ($)	-1787										
17	Mango ($)	-978	-388	-1057	-1057	6193	12059	12059	12059	18464	18464	26851
18	Cassava ($)	-1556	6580	6580	6580	6580	8136					
19	Aggregate net cash flow ($)	-4321	6191	5523	5523	12772	20195	12059	12059	18464	18464	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	161
25	Cassava	0	61	61	61	61	61					
26	Total labour requirement	5	67	100	100	87	163	102	102	149	149	161

A stability analysis of the mango-cassava model is presented in Table 4. Sensitivity analysis using the Excel *Data* then *What-If Analysis* menu options, with 20% pessimistic and optimistic variations in parameter values, reveals that mango yield and price and the discount rate have greatest effect on NPV. Breakeven analysis – using the *Goal Seek facility* in Excel to find the level of each parameter for which overall NPV is zero – is not useful because either species leads to an approximately breakeven financial performance. Scenario analysis – using the *scenario manager* in Excel is used to examine the impact on NPV when a number of parameters are simultaneously adjusted by 20% in pessimistic and optimistic directions – indicates that the NPV would be reduced to less than half if all six parameters simultaneously took pessimistic values. The pessimistic scenario is particularly useful for gaining an impression of how financial performance would deteriorate if there was a general downturn in prices, a destructive weather event or some other unforseen adverse circumstance.

Table 4. Sensitivity, breakeven and scenario analysis for the mango-cassava model

Sensitivity analysis	Pessimistic	Expected	Optimistic	Breakeven values
Mango yield (factor)	0.8	1	1.2	-0.02
	98152	122123	146093	
Mango price (F$)	1.4	1.75	2.1	0.08
	96545	122123	147701	
Cassava yield (kg)	16000	20000	24000	-42700
	114332	122123	129914	
Cassava price (F$)	0.72	0.9	1.08	-1.85
	114137	122123	130109	
Wage rate (F$)	22.27	18.56	14.85	135.2
	118237	122123	126009	
Discount rate (%)	9.60%	8%	6.40%	150%
	107448	122123	139519	

Scenario Summary	Pessimistic	Expected	Optimistic
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%
[illegible]	51849	122121	225364

Table 5 demonstrates the structure of a financial model for an individual species (mango), as parameter, annual cash flows and performance indicators. The annual net cash flows and labour requirements are referenced by the summary sheet.

Table 5. Financial analysis module for a single species – the mango spreadsheet

Financial model for mango

Land area planted (ha)	1.0	Expected yield, yr 4 (kg/ha)	4500
Yield factor	1.0	Expcted yield, yr 5-7 (kg/ha)	9000
Row spacing (m)	9	Expected yield, yr 8-11 (kg/ha)	13500
Spacing within rows (m)	9	Expected yield, yr 12-15 (kg/ha)	18750
Number of trees	123	Transport cost ($/kg)	0.11
Land preparation cost (F$/ha)	614	Labour requirement, year 0	5
Planting materials ($/seedling)	2.2	Labour requirement, yr 1 (days)	6
Planting materials, year 0 ($/ha)	272	Labour requirement, yrs 2-3 (days)	39
Fertilizer, yr 1-3 ($/ha)	103	Labour requirement, yr 4 (days)	26
Fertilizer, yr 4 ($/ha)	412	Labour requirement, yrs 5-7 (days)	102
Fertilizer, yr 5-7 ($/ha)	516	Labour requirement, yrs 8-11 (days	149
Fertilizer, yr 8-15 ($/ha)	619	Labour requirement, yr 12-15 (days	161
Crop protection, yr 1 ($/ha)	174	Mango price (F$/kg)	1.75
Crop protection, yr 2-3 ($/ha)	236	Wage rate (F$/day)	18.56
Crop protection, yr 4-15 ($/ha)	299	Discount rate (%)	8%

Year	0	1	2	3	4	5	6	7	8	14	15
Capital outlays ($)	885										
Fertilizer cost ($)		103	103	103	412	516	516	516	619	619	619
Crop protection cost ($)		174	236	236	299	299	299	299	299	299	299
Transport cost ($)					495	990	990	990	1485	2063	2063
Labour cost ($)	93	111	718	718	476	1887	1887	1887	2759	2982	2982
Total operating cost ($)	93	388	1057	1057	1682	3691	3691	3691	5161	5962	5962
Production (kg/ha)					4500	9000	9000	9000	13500	18750	18750
Revenue ($)	0	0	0	0	7875	15750	15750	15750	23625	32813	32813
Net cash flow ($)	-978	-388	-1057	-1057	6193	12059	12059	12059	18464	26851	26851
NPV($)	98136										
Annual labour requirement (days)	5	6	39	39	26	102	102	102	149	161	161

Table 6 illustrates a more complex agroforestry system, in this case with four species, and with multiple rotations of plantain (a cooking banana species) and kava. Canarium cannot be planted until the second year when shade is available, and has a 30 year life, while Pacific kauri is not logged until year 40.

Table 6. Summary sheet of a more complex agroforestry system – canarium, plantain, kava and Pacific kauri.

AFM5 – canarium (*Canarium indicum*) + Pacific kauri (*Agathis macrophylla*) + plantain (*Musa balbisiana*) + kava (*Piper methysticum*)

Tree or crop species mixture	Year 1	Year 2-6	Year 7-12	Yr 13-16	Yr 17-20	Row spacing (m)	Spacing within rows (m)	Planting density (sph)	Product yield	Yield unit	Product price (vt/kg)	Price unit
Canarium (*Canarium indicum*)	0%	50%	50%	50%	50%	10	9	111	1.0	Factor	50	vt/kg NIS
Plantain (*Musa balbisiana*)	50%	50%	20%	0%	0%	3	2	1667	1.0	Factor	50	vt/kg
Kava (*Piper methysticum*)	0%	40%	70%	70%	0%	2	2	2500	2400	kg/ha	1800	vt/kg
Pacific kauri (*Agathis macrophylla*)	50%	50%	50%	50%	50%	10	9	111	10	m^3/ha/yr	3000	vt/m^3

Shared costs		Common parameters		Notes
Land clearing labour (3 days)	4200	Wage rate (vt/hr)	1400	NIS means nuts in shell (but not husk)
Sundry tools (vt)	25000	Discount rate (%)	8%	Kava roots are dried before selling
Crates and buckets (vt)	10000			Canarium timber is not included in the sensitivity analysis
Knapsacks (vt)	25000			
Land lease fee (vt/ha)	83000			

Annual net cash flows

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	31	40
Shared costs (vt)	-147200														
Canarium (vt)		-39456	-4856	-4856	-8094	-3238	-6475	-25345	23264	-27944	142848	202640	262432	433224	
Plantain, first rotation (vt)	-41785	337402	323515	317340	312567	304991	293913								
Plantain, second rotation (vt)							-16714	134961	129406	126936	125027	121996	117565		
Kava ,first rotation (vt)		-259520	-25280	-36480	-36480	-29200	600892								
Kava, second rotation (vt)							-454160	-44240	-63840	-63840	-51160	1051560			
Kava, third rotation (vt)												-454160	-44240		
Pacific kauri (vt)	-5390	-2406	-2406	-2406	-1604	-1604	-1604	-642	-642	-642	-642	-642	-642	-642	600000
Overal agroforestry system (vt)	-194375	36020	290973	273598	266389	270949	415851	64734	88188	34510	216133	921395	335115	432582	600000
Overall NPV, excl. (vt)	2775365														
Overall IRR (%)	86%														

Note: Plantain is a cooking banana species. Costs and cash flows in this table are reported in Vanuatu vatu

Comparison of performance of the five MSA systems

The aggregate NPVs for an agroforestry system provide an estimate of by how much the grower's wealth would change by adopting agroforestry systems, taking into account the predicted capital outlays, operating costs and revenue generated over the project life. A positive aggregate 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.

Table 7 provides a comparison of financial performance of the five agroforestry systems. Given that the planning horizon for the MSA systems depends on the greatest harvest age of the species included, the models differ with regard to project life, i.e. the number of years for which land must be committed to them. Hence as well as aggregate NPVs, the *land expectation values* (LEV) are reported. An LEV is the discounted sum of an infinite sequence over time of identical projects, and for forestry and agroforestry is known as the *site value*, i.e. what net return the land could generate if committed permanently to a particular agroforestry system. This provides a criterion for comparing MSA systems of differing durations. For very long rotations, the LEV differs little from the NPV. From Table 7 it is notable that models 1 and 3 provide the greatest return. The value of this information is limited in that the site productivity differs between the models; comparison by this criterion would be most useful for comparing returns for alternative species mixtures on similar sites.

Table 7. Financial performance estimates for the five agroforestry systems

Agroforestry system	AFM1	AFM2	AFM3	AFM4	AFM5
Species	Mango, cassava	Breadfruit, pineapple, cassava	Citrus, sandalwood, pigeon Pea	Cacao, sandalwood, sweet potato	Canarium, plantain, kava, Pacific kauri
Project life (yrs)	15	20	20	30	40
No. of species	2	3	3	3	4
NPV – local currency	122123	47105	230473	2693918	2775365
NPV in A$	75716	29205	142893	32327	33304
LEV ($A)	110573	37182	181925	35894	34911

DISCUSSION

Given the kind of information generated in the financial analysis, and particularly the net cash flows and labour requirement in the early years before much revenue is generated, it is possible to provide some policy guidance on what level of support might be required for landholders to be able to adopt particular types of agroforestry systems. This could be linked with the assessment of what form of assistance might be effective. Potential assistance measures might include: market-based instruments (MBI) including subsidies and grants, e.g. free seedlings, assistance with planting, payment for weed control, provision of minor equipment items; joint investment, e.g. plantation joint venture schemes for high-value species; moral suasion (publicising the private and social benefits of tree planting); and broad-based community forestry programs such as joint forest management (practiced in India), community forest user groups (CFUGs, Nepal) and community-based forest management (CBFM, Philippines).

In practice, free seedlings and some extension together with moral suasion are often used to encourage tree planting. In some cases, minor assistance will be sufficient to encourage forestry and agroforestry adoption. In a preliminary survey of agroforestry adoption in Efate, Vanuatu, Harrison and Aising (2015) found that when landholders were asked what type of assistance they would require to expand agroforestry, or adopt agroforestry if not currently engaged in this practice, about half mentioned provision of hand tools (the same numbers as reported financial support). However, for large-scale adoption it is likely that national or regional approaches involving community forestry programs which provide greater levels of organizational support and funding and property rights to some existing forest resources will be required.

Some Challenges for Evaluation of Agroforestry Systems and Suggestions for Further Research

A number of challenges have been encountered in this study. While financial modelling is well established for monoculture forestry and even mixed timber species plantings, modelling of mixed-species agroforestry systems including intercropping targeted at novel tree species for which little financial data are available becomes a much more complex task. There is a distinct lack of information available about the silviculture, harvest age, yield and farmgate timber prices of traditional tree species which have not been grown commercially. A Delphi survey as used for rainforest cabinet timbers in north Queensland (described in Herbohn et al. (1999) and Dayananda et al. 2002, pp. 241-243) could be used to obtain estimates of harvest ages and timber prices for novel tree species in Fiji and Vanuatu.

Some agroforestry costs were found to be particularly difficult to estimate in Fiji and Vanuatu, a notable case being land access costs (lease establishment fees and annual land rental costs), which apparently vary between customary land owners and between locations. As well, depending on the land condition at planting sites, the land amelioration cost can be highly variable, an extreme case being where the land requires a vegetation fallow for perhaps two years before agroforestry establishment can begin.

The MSA financial models which have been developed are deterministic models. While the sensitivity analysis is helpful in providing an indication of how variations in parameters (particularly yields and product prices) will affect financial returns, these do not address the risk of catastrophic agroforestry failure due to wildfire, extreme cyclones or severe pest or disease failure. Measures can be adopted which will minimize the risk of extreme damage, e.g. fire protection measures (described by Harrison and Harrison, 2015), inclusion of cyclone resistant tree species, and use of recommended crop protection measures. Landholders tend to minimize expenditures on these preventative measures. Harrison and Aising (2015) found that their survey respondents were negative about use of chemical fertilizers, but more inclined to use pesticides in their agroforestry.

The models discussed in this paper address financial impacts of agroforestry systems, but do not include non-market environmental and social values also relevant to decision-making. Planting could be undertaken for watershed protection, which would have relatively high cost but low yields, but could be valuable for control of soil loss and downstream flooding. Also, species could be grown which have high traditional values for special buildings, wood crafts or ceremonial events, as additional benefits. Research to estimate non-market values, to be combined with the financial values, would assist policymaking about environmental planting. In other words, to improve the modelling for policy support, it would be useful to supplement the financial estimates with non-market value estimates for environmental and social impacts. Various methods of non-market valuation are available for this purpose, of varying degrees of precision and varying costs. The simplest though somewhat imprecise method would be *benefit transfer*, drawing on databases of non-market values from other sites. 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 1900 studies, and the Review of Externality Database of the European Commission more than 1200 studies. Details of a number of other environmental databases are provided.

MSA systems provide important benefits, but public sector support measures are required to promote them. While various government departments in Fiji have some responsibility for agroforestry, none are the lead agency for agroforestry. Hence development of national or regional agroforestry policy statement (with a similar role to national forestry policy statements which have been developed by many countries) may be warranted. A model on which this could be based is the newly developed Indian national agroforestry policy reported by CCAFS (2014).

Another suggestion for further research is that the financial modelling could be further developed into a *decision-support tool* for use in agroforestry extension. Further validation testing would be desirable for this application. Yield and price data could be refined using the Delphi survey approach as adopted for rainforest tree species in tropical north Queensland. Further validation efforts on the MSA models for Fiji and Vanuatu could be performed by undertaking *face validity* testing with forestry experts, particularly people familiar with mixed-species agroforestry systems adopted on farms or trialled in research projects. It would also be desirable to develop user-friendly input and output interfaces for MSA system models, perhaps including input screens and error trapping, silvicultural and plant protection recommendations, and tabular presentation of result of computer runs.

CONCLUDING COMMENTS

The method of financial analysis for mixed-species agroforestry systems developed in this paper is the result of much development effort on tree and crop financial models and much experimentation in spreadsheet development. The Excel workbook modelling approach involving a summary sheet and modules for each species has proved to be an effective format for the financial modelling. A remaining concern is that there has been insufficient validation opportunities for the MSA financial models and their parameter values. A number of opportunities are identified for improving on and extending the financial analysis of mixed-species agroforestry systems.

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