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How to take advantage of a new crop? The experience of Melanesian smallholders

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Abstract Coconut-based agroforestry systems have a central role in livelihoods on Malo Island in the South Pacific. These mixed plantations provide households with both food and a cash income, thanks to the association in space and time of root crops, vegetables, and cash crops (coconut, cocoa and vanilla). Vanilla has been developed on the island since the year 2000. Farmers have tried to adapt their production systems to include it, with some choosing to do so by associating vanilla with their main cash crop, coconut. A survey of these innovative practices and their economic results conducted in 2005 resulted in an economic modelling of this new agroforestry system with the software Olympe. This study illustrates the use of economic modelling with Olympe to simulate and test new agricultural practices in complex agroforestry systems. The software proved to suit agroforestry systems very well and provided useful information, particularly on economic aspects.

Keywords Small-scale agroforestry · *Cocos nucifera* · *Theobroma cacao* · *Vanilla planifolia* · Diversification · Vanuatu

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Introduction

Malo Island (15°36′S, 167°30′E) is located at a cross point of trade exchanges between the main islands of the Vanuatu archipelago in the Pacific. Coconut-based agroforestry systems are one of the main components of small-scale farming on the island. These systems associate coconuts (*Cocos nucifera*) with cocoa (*Theobroma cacao*) and several types of fruit trees (*Artocarpus altilis*, *Barringtonia procera* and *Citrus* spp.) or nut trees. The main food crops are macabo (*Xanthosoma sagittifolium*), yam (the most common species is *Dioscorea nummularia*), taro (*Colocasia esculenta*), island cabbage (*Abelmoschus manihot*) and sweet potato (*Ipomoea batatas*). These agroforestry plantations combine home-garden traditions that mix vegetables and root crops in a rotational system, including long forest fallows (Allen 2001), with smallholders' cash crop plantations. Coconut and cocoa estate plantations were introduced on the island at the beginning of the nineteenth century by European settlers (Bonnemaison 1996). After Vanuatu gained independence in 1980, most of the estate plantations returned to villagers' ownership, and farmers began transforming them into mixed tree systems. To increase labour and land productivity, people spontaneously associated coconut and cocoa in the same plantations. As the results were convincing, the farmers began planting coconut and cocoa in their new root crops swiddens every year. Coconut, which has long been cultivated for home consumption, moved from staple food to cash crop in family farming (Labouisse 2004).

In the 2000s, the choice in cash crops increased again, with the development of a local market for vanilla and spices. How could smallholders best take advantage of this new economic opportunity? Responses came quickly; local farmers adapted their production systems without giving up their previous productions and while maintaining their food crop cultivation. They tested different options for introducing vanilla to their farms, such as cropping vanilla (*Vanilla planifolia*) under coconuts.

This study compares the economic results of the main associations of coconut, cocoa and vanilla that were observed in Malo, and discusses the advantages of the different systems and the choices made by smallholders. While in countries such as Indonesia or the Philippines, agroforestry plantations are increasingly being replaced by monocultures, the people of Vanuatu chose diversification of production rather than specialisation, at both the household and the plot levels. Assuming that the economic results of the different types of plantation are determinant in smallholders' decisions, we used three economic indicators to compare the plantations: return to land, return to labour and labour needs across a year.

Materials and methods

A combination of surveys, field observations and measures was used to determine farmers' strategies, agricultural practices and decision-making processes, and to assess the performances of agroforestry systems in terms of yields, labour needs and incomes. The data collection was conducted in 2005 (Feintrenie 2006), during 6 months of field work, from May to October).

Interviews were conducted of a sample of 30 households, to collect data on cropping practices, inputs (such as fertilizers, pesticides and tools), labour needs, prices and yields. This information was confirmed by a literature review of the most recent studies conducted on Malo Island: Allen describes the local agrarian system (Allen 2001) and the traditional staple food gardening system (Allen 2000); a detailed typology of the coconut-based agroforestry systems was carried out by Lamanda et al. (2006). The spatial and temporal dynamics of a family farm were also captured during these interviews; the history of the household and the distribution of the plots used by the household across time were recorded, along with details on the management of the plots and the tenure status. Farmers' strategies and decisions regarding the allocation of plots to one crop or another were discussed.

Coconut–cocoa and coconut–vanilla agroforestry systems were studied using the synchronic approach, which permits the extrapolation of temporal dynamics from a set of plots of different ages. This approach is relevant only if the spatial distribution of plots of different ages in a relatively homogeneous environment at a given point in time can be considered equivalent to the different stages of a plantation over time (Pickett 1991). Four stages were selected to describe these agroforestry systems according to their spatial and temporal components along the coconut life cycle. The definition of these stages was based on the description of coconut-based agroforestry systems made by Lamanda (Lamanda et al. 2006). Measurements in the plots aimed to confirm the information available from previous studies (Allen 2000; Lamanda et al. 2006); therefore, a small sample of plots was considered sufficient, as long as no contradictions with the literature or with farmers' interviews were observed. Three representative plots were chosen for each stage in the same morpho-pedological unit, with constant agricultural practices over time. The sample was composed of 12 plots of coconut–cocoa plantations and 3 plots of coconut–vanilla. The floristic composition of the plots was assessed to get a precise description of the cropping system according to the age of the main perennial crop, the coconuts. Useful species were numbered and their productions were measured. Interviews with farmers, using the same sample of 30 households, confirmed the data on plot floristic composition according to the age of coconuts, and yields of the main species according to the age of the plants.

Modelling of economic results was done using the software Olympe (CIRAD et al. 2007; Deheuvels and Penot 2007). Olympe is a decision-support software for agriculture. It combines a database 'ready to fill' with economic information on prices, productions and households with an accounting calculator which allows the automatic computation of economic indicators. The software can also be used as a simulator to test a change in the farming system or to evaluate a farm's resilience to risks such as low harvest or price drop (CIRAD et al. 2007). Yields, prices, costs of production and labour needs were processed in the Olympe software and gross margins were calculated on the basis of a 1-ha plot, with details of each perennial crop and food crop (Feintrenie 2006). Economic modelling allowed the simulation of economic results over the coconut production cycle of 80 years. First, a comparative analysis of coconut–cocoa and coconut–vanilla plantations using economic indicators (return to land, return to labour and labour needs across a year), and exposed over the coconut production cycle, revealed the advantages and constraints of the two agroforestry systems. Second, the possibilities of combining the two cropping systems on a family farm were simulated and evaluated using Olympe.

Results

Coconut-based agroforestry systems in family farms in Malo

Family farms in Malo have a median size of 5–10 ha of cultivated land and extensive production systems. The main labour force is the family, with labour groups organised among neighbours for some activities (such as the copra harvest). The farming system is based on a combination of perennial cash crops and annual or pluri-annual food crops. Agroforestry systems usually occupy half of the cultivated land area and are the first installed by a young household (100% of respondents). Figure 1 shows the dynamics of crops implementation in space and time. Traditionally, farmers clear a plot of forest every year to install a garden, which combines food crops and perennial cash crops; this garden is usually about 625 m^2 (or 1/16 ha). Perennial plantations thus increase at the same rate as forest clearance. A household possesses a quite constant surface area of garden in its first, second and third years every year until all the land is planted perennially. A minimal surface of forest reserve, often about 1 ha, is usually preserved for use for the home garden once intercropping of food crops in plantations is no longer sufficient to meet the family's needs. Allen (2001) describes the traditional home-garden system as the rotation of root crop gardens and long-term bush fallows (more than 15 years). One farmer used to cultivate a plot only once, and not come back in the same place after several years but rather move to a new stand of forest for every new home garden. Our interviews suggest that the increasing population density on the island has led to more individual land appropriation. As a consequence, 1 ha of land reserve is not large enough to allow farmers to keep a long fallow rotation with their home gardens. Ninety per cent of the households surveyed follow a complex rotation system, with a combination of long fallows and short fallows. A garden is cultivated for 4 years. The fifth year is the beginning of a short fallow period of 2–3 years. This short rotation of 6 or 7 years, including the food garden and short fallow, repeats three or four times. Then, after about 20 years, the place is left to long fallow (20 years), and a new forest plot is cleared for gardening. Most often this second site is far from the house, because all the nearest lands have already been planted with perennial crops (80% of respondents). Within that scheme, a farmer can exploit two to three different sites for gardens during his/her life.

The progressive establishment of crops allows a succession of productions. For a 1-ha plot, the first 20 years are dominated by food crop production; perennial crops then take the lead (100% of respondents follow this succession). Food crops are mainly destined for home consumption but they can also be sold in the local market to get some cash income (20% of respondents said they sell vegetables in the local market once or twice every 2 months). The presence of food crops during the very first years of cultivation gives young households an opportunity not to indebt themselves during the immature period of cash crops (confirmed by 50% of households), which can be considered an investment period. After these 20 years, corresponding to the progressive establishment of perennial crops and 4 years of gardening, perennial crops generate a regular income that can last 80 years for coconuts. Therefore, the progressive establishment of crops allows the family to spread out its income, to adapt to its means during the period and especially to the family labour force, and to adjust to the family's needs for a cash income (Feintrenie et al. 2010).

Shifting agriculture is usually practised in areas of low population density and where arable land is not

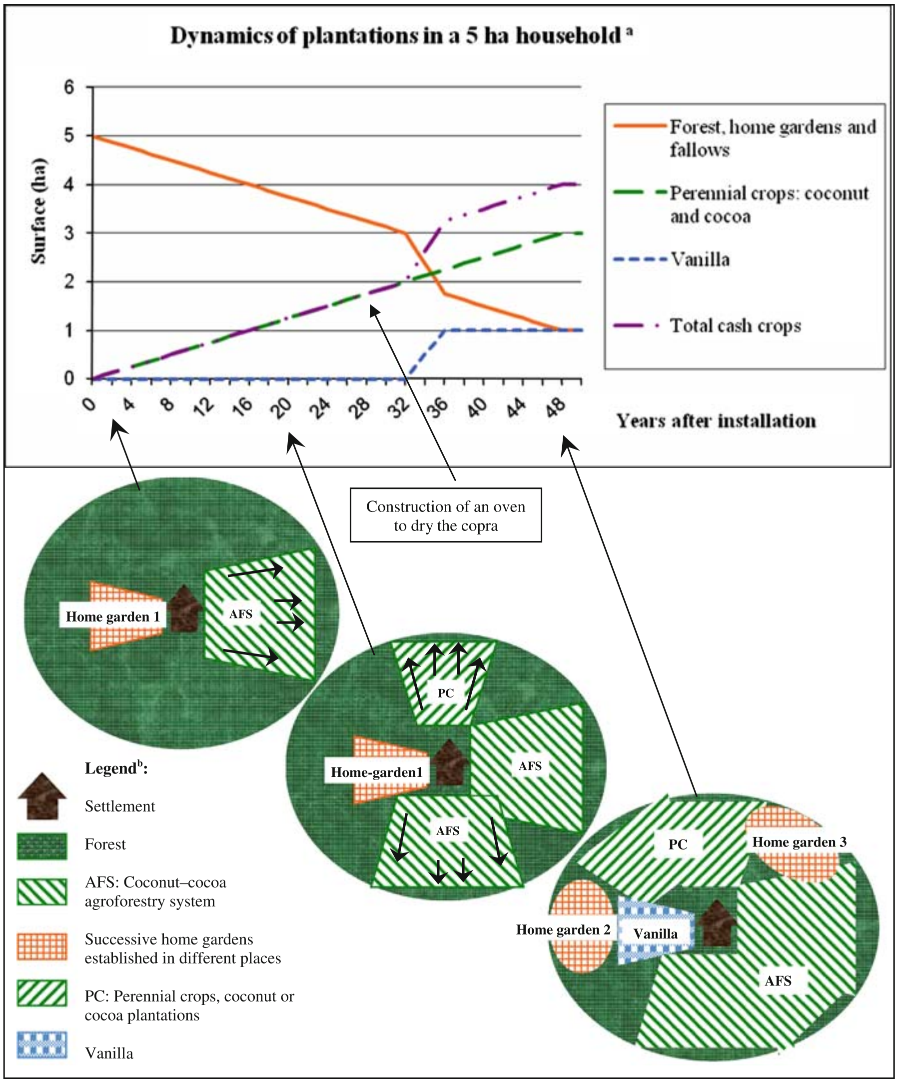

Fig. 1 Spatial dynamics of a family farm across time. The graph (**a**) illustrates the land area owned by the household across time, and how it is shared among the different land uses. Three pictures (**b**) map the relative positions of plantations and home gardens around the house, at three points in time. *Arrows* represent the progressive plantation of a plot

limited in either surface or access (Mazoyer and Roudart 1997). However, this situation is currently changing on Malo Island. According to the inhabitants, land pressure is rapidly increasing and access to land can be difficult. Therefore, perennial plantation is also a way for farmers to appropriate and to claim land. The establishment of huge areas of extensive plantations is a low-cost strategy to increase land property with no possible contestation.

Coconut–cocoa agroforestry system

The values presented below are the results of the computation of the economic data gathered in the field, using the Olympe software. We defined a typical coconut–cocoa agroforestry system of 1 ha, based on the data collected in the plots and during the interviews. A 1-ha plot of coconut–cocoa agroforestry is established step by step during 16 years, with the clearance of a small forest plot (1/16 ha) every year. The main work during the establishment phase is the forest clearing and garden cropping. Little work is needed for the young coconuts or cocoa trees. The busiest period is from August to October, with the harvest of yams and taro, but labour demand still only reaches 92 h/month, or about 3 h/day for one person (Fig. 2c: Work table of a coconut–cocoa plantation during the immature phase). If one person works 8 h/day and 26 days/month, then available labour is 208 h/month. Thus, one person can manage 208/92 = 2.25 ha

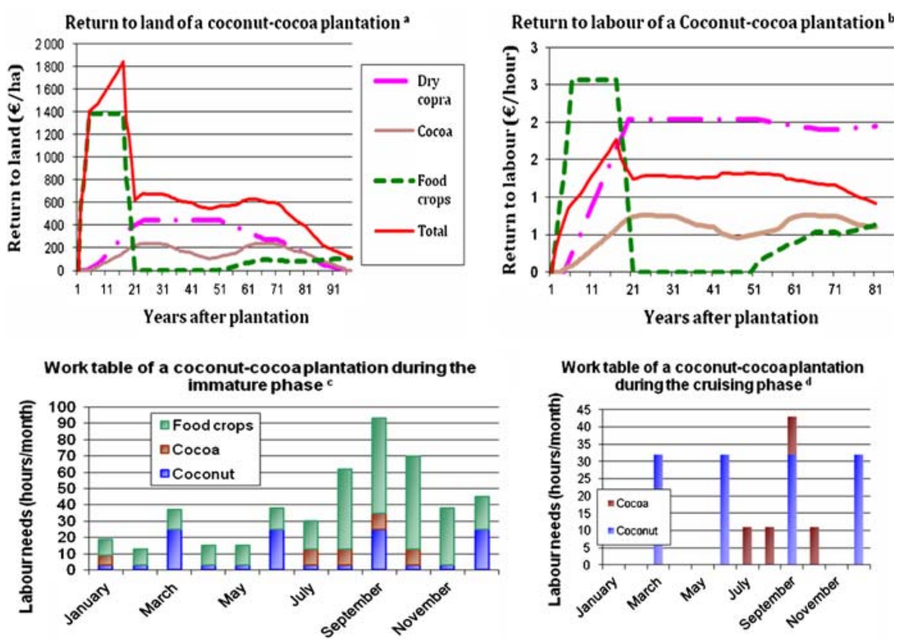

Fig. 2 Return to land (**a**) and labour (**b**) of the different components of the coconut–cocoa-based agroforestry system and work tables during the immature (**c**) and the cruising (**d**) phases. The return to land (**a**) is the economic product of 1 ha in 1 year; all costs (inputs, initial investment, labour) are included in the calculation. The return to labour (**b**) is the return to land divided by the number of hours worked in 1 year. These two indicators were estimated for the whole production cycle of the plantation, represented on the graphs according to the age of the plantation. The immature phase represents the first 4 years of a plantation, before the production of coconuts (coconuts are 'immature'); diagram **c** shows the labour needs of a 1-ha plot during the 20th year after the first coconuts were planted. The 'cruising phase' is the period during which the main crops (coconuts and cocoa) are productive and production is at its maximum. Diagram **d** represents the labour needs of the same plot during the 35th year after the first coconuts were planted, which is during the cruising period. The productivity of a monoculture coconut plantation was estimated as similar to the coconut productivity of an agroforestry plot (result of the interviews). Thus the lines representing 'dry copra' (graphs **a** and **b**) can be considered as the returns to land and labour of a 1-ha coconut plot, and can be compared to the results of an agroforestry plot represented by the lines for 'total' (graphs **a** and **b**). Data were collected on a sample of 15 plots (2- to 4-ha plots) for production measures and interviews of 30 households for labour needs, prices, inputs and yearly work table. The field survey was conducted in 2005. Data were processed using the Olympe software to calculate the economic indicators throughout the whole production cycle

of a coconut–cocoa agroforestry system during the establishment period. Using the same calculation, it appears that one person can manage 6.62 ha of a mature coconut–cocoa agroforestry system, when production is at its highest level, which we call the 'cruising period' (Fig. 2d: Work table during the cruising phase of a 1-ha plot in the coconut–cocoa agroforestry system). Return to land is at its maximum during the establishment of the plantation (Fig. 2a: Return to land of a 1-ha plot in the coconut–cocoa agroforestry system); it reaches more than 1300 €/year after 5 years (for a cultivated surface of 3125 m^2 at that time). This high productivity of food crops maintains itself as long as the farmer enlarges the plot, that is, during 20 years for a 1-ha plot. Then, the annual gross added value in the cruising phase (for our example of 1 ha of plantation) decreases to an average of 250 €/year (Fig. 2d). Thus, for 6.62 ha of plantation, the monthly gross added value would be $250/12 \times 6.62 = 138$ €/month. This amount is nearly equivalent to the net added value or to the agricultural income, because of the very low costs of production (very cheap tools, no expensive building or materials, no tax, no subvention, etc.). Therefore it can be compared to the minimum wage in Vanuatu, which was 130 €/month in 2005 (Radio New Zealand 2005), compared with 138 €/month produced by the plantation with less work.

Return to labour is also high during the establishment phase, with an average of 2 €/h (Fig. 2b: Return to labour of a 1-ha plot in the coconut–cocoa agroforestry system). Then, during the cruising phase, return to labour stabilises at around 1.10 €/h for 1 ha of plantation. This too is higher than the national minimum wage hour income.

Coconut–vanilla agroforestry system

Vanilla has been cultivated on Malo Island since 2000; it is presently the fashionable diversification crop for coconut–cocoa plantations. It is cultivated either in monospecific plantations on *Glyricidia* sp. or *Erythrina* sp. live stakes, or under coconuts. As it was still a new crop at the time of the field work (2005), cropping schemes were not yet strictly fixed by farmers, who were trying different practices, among which was association with coconuts. In Malo, vanilla was found associated with coconuts of every age, from 4- to 40-year-old plantations. Others were planted at the same time as new coconut plantations, but this met technical problems because of the spatial bulkiness of young coconuts; it is difficult to intercrop vanilla between coconuts lines before the crown grows higher than 4 m. Because of this inconvenience, we assumed that in the future farmers will plant vanilla only under coconuts older than 8 years. Shading can be beneficial for vanilla at several stages, but coconut shading may cause some difficulties because it cannot be controlled throughout the year and palm or fruit falls can hurt vanilla ropes. On the other hand, as vanilla plants need inert compost to grow, coconut is very complementary, as coconut husks and shells are layered on the soil surface around each live stake. This mulch provides the vanilla's aerial roots with moisture, shelter and nutrition.

Economic performances of the coconut–vanilla agroforestry system were estimated using the same modelling as for the coconut–cocoa system. The same dynamic of establishment was modelled: 1-ha plot cleared by sectors of 625 m^2 every year, plantation of coconuts in the first year, food crops intercropping during the first 4 years and then plantation of vanilla in the fifth year. The results are presented along the whole length of the coconuts' production life, namely 96 years. We considered a plot of 1 220 vanilla ropes/ha, with a production estimated through surveys at 24.4 kg/ha at 3 and 4 years, 48.8 kg/ha from 5 to 8 years, then 24.4 kg/ha at 9 and 10 years. Vanilla ropes are replaced in the 11th year, when there is no production.

The analysis of the work table of a 1-ha plot in the coconut–vanilla agroforestry system (Fig. 3c: Work table during the cruising phase of a 1-ha plot in the coconut–vanilla agroforestry system) shows that it has a high labour demand. A single person can manage only 0.19 ha of this cropping system because of the huge amount of work needed during the flowering and harvesting periods, from September to December (the same calculation technique as above). Pollination must be done by hand as the natural agent of fecundation, a small bee, is not in Vanuatu. This work and the harvest are carried out every morning for 4–5 months.

Return to land is very high, at between 3000 and 4500 €/ha a year (Fig. 3a: Return to land of a 1-ha plot in the coconut–vanilla agroforestry system), with an average of 3607 €/ha in a year, or 300 €/ha a month. This result is because of the high price of vanilla in Vanuatu, especially in comparison with copra or cocoa. Nevertheless, this high return to land is moderated by the low return to labour (Fig. 3b: Return to labour of a 1-ha plot in the coconut–vanilla agroforestry system). Indeed, return to labour is around 1 €/h, which is half the coconut return to labour or 4–5 times less than the food crops' return to labour. Thus vanilla can yield a lot by hectare, but only with a huge labour demand throughout the year, which limits the possibility of relying on day workers. The valorisation of 0.19 ha by one person is only at 685 €/year or 57 €/month.

Thus the establishment of a coconut–vanilla agroforestry system responds to different farmers' objectives and strategies to those of a coconut–cocoa agroforestry system. The association of vanilla with coconuts is interesting for a farmer who has limited access to land but available labour. On the other hand, a strategy of land occupation by extension of plantations every year will be better served by a coconut–cocoa system, as it is less demanding in terms of labour.

Comparison and combination in a coconut–cocoa–vanilla agroforestry system

These first analyses of the economic returns of vanilla and cocoa under coconut cropping systems demonstrate that these two systems are promising and

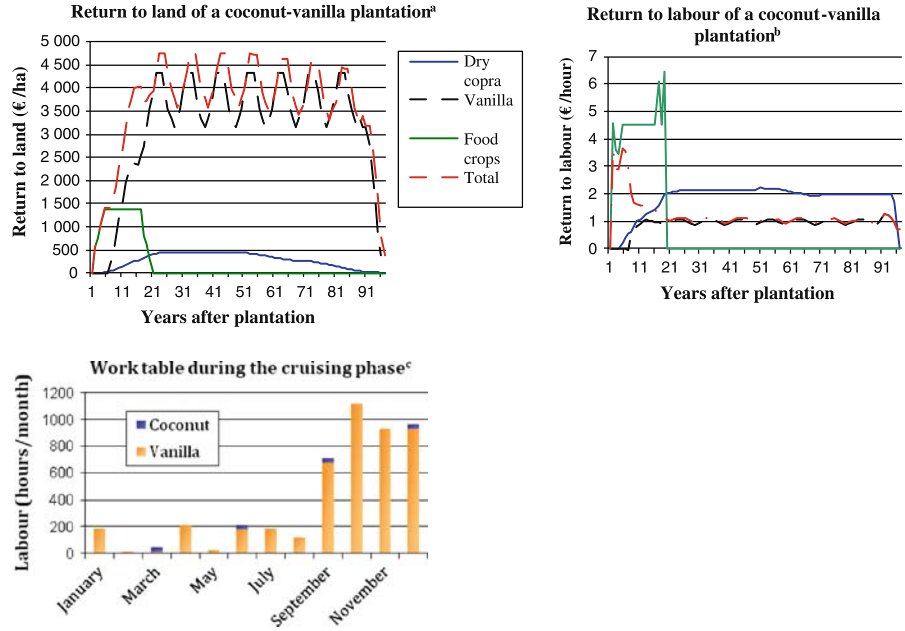

Fig. 3 Return to land (**a**) and labour (**b**) of the different components of the coconut–vanilla agroforestry system and work table (**c**) for the 35th year after the first coconuts were planted, which is during the cruising phase. Data were collected on a sample of 3 plots (0.5- to 1.5-ha plots) for production measures and interviews of 10 households for labour needs, prices, inputs and yearly work table. The field survey was conducted in 2005. Data were processed using the Olympe software to calculate the economic indicators throughout the whole production cycle

answer the complementary needs and strategies of farmers. A second step in the search for the best way to integrate vanilla into small family farms is to evaluate the feasibility and profitability of combining vanilla with both the main crops. For this, a new economic model is proposed. The aim of this exercise is to test the new cropping system observed in the field—vanilla under coconut—by simulating its economic profitability over a whole production cycle. It is once again based on a 1-ha plot, progressively planted by sections of 625 m^2. In this model, vanilla and cocoa are spatially separated; indeed, their association is not technically suitable. The dense canopy of cocoa trees creates a deep shade that compromises vanilla production. Thus the combination of these two crops is possible only in a segregated manner; integration thus takes place through the farming system but not at the plot level. Based on field observations, and to be as close as possible to farmers' actual management, it was decided that the first 14 sections of the hectare plot would follow the model of the coconut–cocoa system and that the remaining two would follow the coconut–vanilla system. When the whole of the 1-ha plot is planted, it is composed of 0.87 ha of cocoa under coconuts and 0.12 ha of vanilla under coconuts. As for the first models described in the paper, in each section of 625 m^2, food crops are grown under coconut during the first 4 years, intercropped with cocoa or vanilla.

The economic results are presented using the same kinds of graph as for the two previous systems. Return to land is quite high (Fig. 4a: Return to land in the coconut–cocoa–vanilla agroforestry system) with an average of 792 €/ha for the whole cropping cycle. As for the first models, food crops increase return to land during the planting phase. Nevertheless, during the cruising phase, from the 17th to 71st years, the average is 747 €/ha a year, or 62 €/ha a month, which is higher than in the cocoa–coconut system. The work table (Fig. 4c: Work table of a coconut–cocoa–vanilla agroforestry plot during the cruising phase) for 1 ha shows the high labour demand of vanilla. However, the combination of only 0.12 ha of vanilla with 0.87 ha of cocoa results in a labour demand that is intermediate between the two initial systems. The average return to labour is 1.55 €/h for the whole cycle, or 1.17 €/h during the cruising period (Fig. 4b: Return to labour in the coconut–cocoa–vanilla agroforestry system). This is slightly higher than the coconut–cocoa-based system (1.10 €/h). The maximum monthly labour demand is 145 h in October and December. This allows one person to manage 1.43 ha of this agroforestry system alone (same calculation as

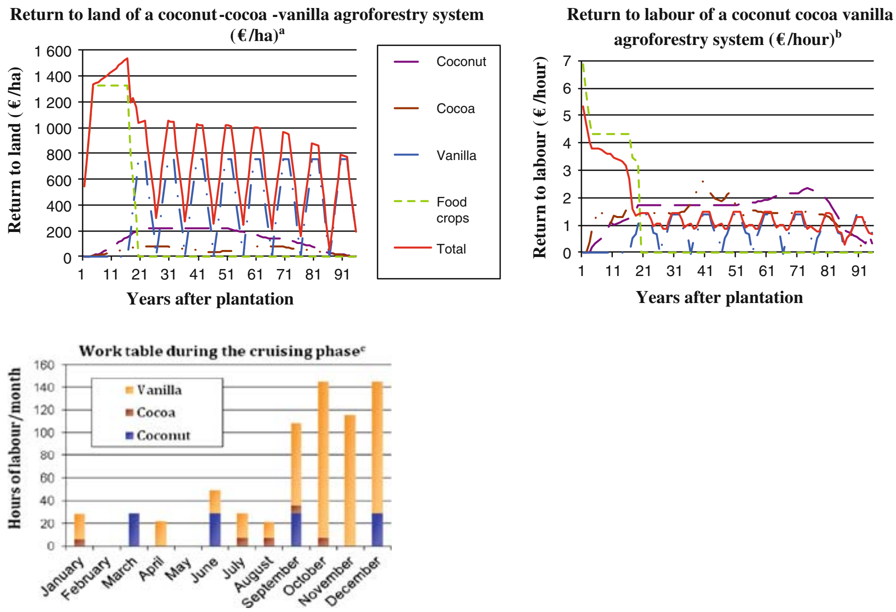

Fig. 4 Return to land (**a**) and labour (**b**) of the different components of a coconut–cocoa–vanilla agroforestry system and work table during the cruising phase (**c**). This figure presents the results of the modelling exercise. It shows the evolution of economic indicators for a fictive plot of coconut–cocoa–vanilla, calculated using the Olympe software, and based on data collected in 2005 in 15 plots and interviews of 30 households

above: (8 h/day × 26 days/month)/145 h/month = 1.43). With a plot of 1.43 ha, one person could obtain a net added value of 1 071 €/year, or 89 €/month. The employment of seasonal workers for the harvest of vanilla from October to December is an alternative that would allow one person to manage a larger area of land. Indeed, during the rest of the year, the farmer would be required to spend less than 35% of his/her time on his/her plot of 1.43 ha (based on 208 work hours/month). Furthermore, as hand-pollination and fruit harvest are done in the early morning, the farmer will have some free time in the afternoon during the flowering and harvest seasons. The farmer can valorise this ‘free time’ by conducting other activities, especially off-farm ones.

Discussion

The cropping systems presented above have some common advantages linked to the successive association of perennial cash crops with annual and pluri-annual food crops. In the first years, food crops meet the family’s needs both for home consumption and for the possibility of trade in local markets. Their high productivity, in terms of both labour and land, lasts for 20 years in the case of a 1-ha plot established progressively by plots of 1/16 ha. The long life of coconuts, up to 80 years in Malo, allows a constant income for many years. Furthermore, coconut has no harvest season and production is regular throughout the year. This allows farmers to adapt to labour availability. Coconuts are also used as a cash reserve, with the harvest taking place when cash is needed. The possibility of trade always remains, even when the price is low. Last but not least, as a perennial crop, coconut is a good mean of land appropriation.

Cocoa and vanilla both bring some added value to coconut plantations. In the case of extensive practices, with nearly no fertilisation and in rich soil, coconut productivity is not decreased by the association of a second crop. Thus, this association of two cash crops in the same plot increases the return to land; furthermore, it results in no more labour than if the two crops were cultivated in separate plots.

Vanilla needs more labour than cocoa or coconut, but the type of labour needed is less painful and less physically demanding than for coconut or cocoa plantations; it involves daily maintenance work throughout the whole year, including delicate work for hand-pollination, which demands special skills. The people of Malo appreciate this aspect, declaring in the surveys that they prefer to spend hours at a vanilla plantation than harvesting copra or cocoa (stated by 80% of respondents). This inclination towards horticulture was noted by Bonnemaison (1996) in his first description of the Vanuatu people. The high return to land of this crop is an opportunity to respond to the land shortage that can already be predicted for Malo Island. Although cocoa offers a better return to labour, it would not be competitive in a situation of land shortage. Thus, farmers' current strategy of diversifying their production and activities may also lead to a new orientation of agriculture in Malo. Indeed, diversification could be a transition during which smallholders evaluate a new option for production, which was illustrated by numerous cases (Feintrenie and Levang 2009; Kumar and Nair 2004; Mazoyer and Roudart 1997; Michon 2005). If farmers appreciate the new crop as a sustainable and profitable crop, they may turn to more specialised production of vanilla and abandon cocoa cropping. Nonetheless, the complementarities of the crops favour diversification through agroforestry, in terms of spatial occupation of the plot, both above (compatible heights of plants) and below ground (root systems spatial distribution, see Colas 1997), and in terms of labour needs during the year. It is a nearly no-cost way to increase farmers' incomes by increasing plant density in the plot without adding to the costs of inputs, only adding labour. This strategy is favourable, given the absence of incentives from the government agricultural extension services or the buyers of agricultural products to use fertilisation and pesticides and to intensify agricultural practices. On the contrary, the main buyer of Malo's spices and vanilla has sponsored the certification of the island as organic farming for vanilla and spices. The influence of regional stakeholders in the way smallholders conduct their plots is thus clearly visible. In other countries, an opposite influence can be observed. The Asian examples of the disappearance of rubber agroforests in Indonesia (Feintrenie and Levang 2009) or of the intensification of cocoa agroforestry plantations in Indonesia (Franzen and Mulder 2007) and the Philippines (Eder 2006; Michon 2005) illustrate the strong forces of agribusinesses in promoting intensified monoculture plantations.

Diversification of production gives greater robustness to a farming system (Franzen and Mulder 2007; Krummenacher et al. 2008; Marschke and Berkes 2006; Penot and Ollivier 2009), but we should not forget that there are some limitations. The more crops one farm combines, the smaller the produced quantities, which leads to less economy of scale and inability to meet the demands of international traders, who usually require large and regular quantities of produce. However, this problem is solved by the Malo island's regional specialisation, where the farmers all cultivate the same main cash crops. Another limit of biodiversity rich systems is their lower productivity in comparison with intensive monoculture (Belcher et al. 2004). As Swift et al. (2004) underlined, biodiversity is unlikely to be maintained at the plot or farm scales if there is neither utilitarian benefits or direct use nor income generation to justify it. Schroth et al. (2004) also discussed the difficulties of integrating biodiversity conservation to agricultural production. In the coconut-based system presented here, the progressive plantation of perennial crops allows the farmer to combine traditional home-gardens and cash crop production during a long period (20 years for a 1 ha plot), integrating in the same plot two different goals. As it was emphasized by Caillon and Degeorges (2007), agroforestry in Vanuatu offers the possibility "to reconcile systems of different values and representations".

The combination of cocoa and vanilla in a farming system leads to fairly good economic results. The modelling simulation of this agroforestry system is very close to what farmers were testing in 2005 and to the way they manage their farms. The return to land of this combined plot is higher than that of the coconut–cocoa plantation. This system also partly responds to the coming land shortage by freeing land and time for other crops (either food crops or cash crops). Nevertheless, this spontaneous diversification process through vanilla was possible only thanks to the combination of suitable climate conditions, the presence of traders demanding the product, availability of land and the new crop's compatibility with the existing farming system. As this situation is exceptional, it would be nonsensical to promote the adoption of this vanilla–cocoa–coconut plantation in other places without further study. Vanilla has been cultivated in Malo for only a few years; therefore, its adaptation to the physical environment is not yet certain. Indeed, it is suspected that the climate has a big impact on the success of vanilla crops. Vanilla production is optimum only after one or two relatively dry months, between June and August, succeeded by a few cold nights, which induce the emission of flower buds. The first years of production were promising. It is a concrete example of farmers' innovation through diversification and a good illustration of how agroforestry techniques can respond to land shortage, or at least improve livelihoods without demanding added investment in land or money.

The method followed in this study, which combines surveys, measures and economic modelling, allows the quick evaluation of the performance of existing cropping systems and the potential of new ones. However, this method has some limitations, mainly the difficulty of assessing the high diversity of agroforestry plantations (management, composition, ecological conditions, etc.) and the risk of modelling an 'economically' ideal system that cannot be implemented in the field. Nevertheless, used carefully, economic modelling creates a theoretical representation of a complex system which allows comparisons with other crops and tests of new models. Olympe software is well adapted to complex agroforestry systems; productivity can be entered per tree as well as per hectare, and a plot can be defined very precisely by its floristic composition in useful plants. This software is freely available on Internet with supportive documents (CIRAD et al. 2007) and can be used by agroforestry practitioners to simulate new agroforestry combination or evaluate household economic resilience to shocks such as economic crisis or bad harvest.

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