New opportunities for small farmers of the Amazon to strengthen hazards resilience while preserving their forest. Field experiments combined with multi-agent modeling

4 authors, including:

Pierre Bommel
Cirad - La recherche agronomique pour le développement

Plinio Sist
Cirad - La recherche agronomique pour le développement

Amaury Burlamaqui Bendahan
Brazilian Agricultural Research Corporation (EMBRAPA)

New opportunities for small-scale farmers of the Amazon to strengthen hazards resilience while preserving forests – field experiments combined with agent-based modelling

Convening lead author: Pierre Bommel

Lead authors: Marie-Gabrielle Piketty and Plinio Sist

Contributing authors: Amaury Burlamaqui Bendahan and Tienne Barbosa

Abstract: This paper introduces a simulation model focused on smallholder practices and labour management that is used to assess the long-term impacts of alternative land-uses in the Amazon region. Our objective is not to provide a tool for decision-makers but rather to inform the debate on rural practices and their likely consequences on forests resources, income generation, and land-use trajectories. We discuss the advantages and limitations of forest management (FM) for timber and permanent field of annual crops (PFAC), based on conservation agriculture, and the way in which they constitute management options with potential to protect forests while improving smallholders' livelihoods. Our model shows that subcontracted sustainable FM for timber (logging operations outsourced) in legal reserves and PFAC are not miraculous solutions that allow smallholders to prosper while preserving their forests. However, the additional earnings originated from FM facilitate the family's installation phase, which is often a critical period. Since income from FM can help farmers cultivate productive crops and pastures, it improves resilience to hazards (sickness and accident) that are frequent in the Amazon. In addition, since PFAC is an intensification technique, it has positive effects but only when adopted after the installation phase. In that case, it provides some additional profits by recovering degraded pastures. Considering a scenario with hazard probability and where 50% of smallholders' lands have to be dedicated to forest protection, adopting FM and PFAC appears to be a win-win solution for smallholders.

Keywords: Brazilian Amazon, forest management, tropical timber, conservation tillage, agent-based model, multi-agents system

4.1 Introduction

With an extensive surface of 7 million km^2, the Amazon plays a major role in water and carbon cycles, therefore deforestation occurring in the region may have severe impacts on these cycles at both regional and global scales (Davidson et al. 2012). Smallholders are responsible for substantial amounts of forest clearing (20% to 30% according to Fearnside 2008). Colonisation of the Brazilian Amazon started in the early 1970s and led to the creation of more than 500 000 km^2 of agrarian settlements occupied by small farmers (Menton et al. 2009). Deforestation mainly occurred in three states: Pará, Mato Grosso, and Rondônia (INPE 2011). The Brazilian Forest Code states that 50% to 80% (according to local regulations) of landholdings must remain permanent forest reserve in which forest management plans can be executed only after approval by the local authorities. Although in practice, many landholdings have already been deforested beyond these limits, more than 12 million ha of permanent forest reserves are still held by small farmers (Amaral et al. 2007).

In the eastern Amazon, where cattle breeding is a common farming activity, traditional extensive livestock systems have expanded on smallholdings, which has resulted in significant deforestation. This expansion has enabled the smallholders to maintain their production in a context in which productivity tends to decrease over time. Pasture degradation regularly occurs due to inadequate pasture management practices or repeated burning, which in turn affects ranching productivity (Vosti et al. 2002, Walker et al. 2002). Therefore many smallholders with farms originally under forest cover have rapidly become limited in terms of profit accumulation without land expansion (Pacheco 2009). Although conservation agriculture techniques could be an alternative to preserve soil fertility and avoid deforestation, small-scale farmers usually do not have the technical knowledge or the financial capacity to implement such an alternative.

In the framework of the Forest and Agriculture (FloAgri) project funded by the European Union, such alternatives, called forest management (FM) for smallholders and permanent field of annual crop (PFAC), were tested with smallholders of the Transamazon highway (Pará state) through the implementation of FM plans and conservation agriculture systems (Sist et al. 2010, Scopel et al. 2013).

In order to assess the long-term impacts of the adoption of these alternative land uses, we adapted an agent-based model (ABM), initially developed to explain deforestation processes and describe the expansion of pioneer fronts in the Transamazon Highway region (Bommel et al. 2010). By adding new land-use activities (FM and PFAC), we discuss the advantages and the limitations of such alternatives and the way in which they can help protect forests while improving smallholder livelihoods.

The aim of this chapter is to test whether FM may be appropriate for smallholders and to identify the most important conditions that foster FM adoption in the Brazilian Amazon, our ABM helps to inform the debate on rural practices and their likely consequences at the farm level. Unlike top-down approaches often directed to policy-makers, our model focuses specifically on smallholders' decisions to better understand the constraints they experience in farming and the challenges they face in adopting more sustainable practices. Thus, this chapter aims to shed new light on how FM can contribute to the income of small farmers and why, in some cases, FM improves the resilience of these families against hazards such as illness or accident. By assessing the range of choices smallholders have and under which conditions they can integrate forest management, livestock, and agriculture, this chapter gives new elements to what seem to be the prerequisite conditions for positive changes. These issues are currently important in the debate around the new reform of the Brazilian Forestry Code. The model helps in consideration of future scenarios of FM by smallholders in the Amazon region, providing a different perspective on sustainable FM related to broader land-use decisions at the farm level.

This chapter is organised in five sections, including this introduction. The second section briefly describes the structure of the model and the dynamics of the entities. The third section presents some results of six land-use strategies in various circumstances. Then, before the conclusion, the fourth section discusses the relevance of such a model to point out how and why different contexts and policies can enhance or curtail the adoption of FM.

4.2 Comparing various land-use strategies using an ABM

The ABMs facilitate the understanding of human-environment interactions by pointing out the implications associated with various options for action. By designing the basic entities of a system and describing their distinctive behaviours, it is possible through the simulations to observe what can emerge at the global level of the system (bottom-up principle). When including the spatial dimension (with localisation of agents' activities), we obtain some dynamic maps. Because few ABMs have been designed for the Amazon region (Deadman 2005, Aguiar et al. 2012), this paper contributes to a better understanding of the underlying processes involved in land use.

4.2.1 Purpose of the model

ABM can be useful in management decisions (Bousquet and Le Page 2004). Yet it is important to stress that our ABM is not intended for optimisation of land uses. The purpose is not to predict the best way to achieve a desired situation but rather to explore the feasibility of various land-use strategies and their implications for smallholders (see Börjeson et al. 2006). Thus, the model seeks to evaluate the strict compliance with environmental law and the long-term effects of two alternative land-use activities. These land uses are PFAC based on conservation agriculture systems (no-tillage) and FM for timber in forest legal reserves (LRs). In our model, a logging company contracted by the farmers carries out FM. These partnerships or subcontracts between farmers and logging companies are very common in the region although they are usually quite informal. The model outputs allow us to compare the

Table II 4.1 Description of the six scenarios to assess the economic and ecological viability.

Initial conditions	Strategy	LR compliance	Specific activities
◆ Same family structure (ex: 3 adults + 3 children) ◆ Same initial cash ◆ Same farm size ◆ Same initial land cover ◆ Same soil types	Breeder	*No*	A: Standard activities
		Yes	B: A + Forest management
		No	C: A + Permanent crops
		Yes	D: B + C
		Yes	E: A + LR compliance
		Yes	F: C + LR compliance

economic performance and environmental impacts of smallholders' practices. We did not use sophisticated agent approaches (such as BDI architecture[(1)]) but a heuristic household decision-making structure based on observations in the field, interviews with famers, and experts' descriptions of rural practices (Moran 1989, Veiga et al. 2003, Veiga et al. 2006).

4.2.2 The overall methodological approach

The main principle of our modelling approach is to compare various production activities starting from the same initial conditions. Considering that small-scale farmers in the Amazon are mainly focused on livestock production, each agent adopts cattle breeding as the main production strategy along with a set of specific additional activities.

From each initial state, identical for each agent, six simulations are run in parallel according to a supplementary specific activity that the agent has to perform (Table II 4.1). The first scenario (*StandStrat*, considered as the control scenario) corresponds to the business-as-usual breeder strategy, for which the agent invests mainly in livestock without preserving his LR. When an FM activity is included (*FmStrat*), the agent has to delimit and protect a part of the forest within his landholding, from which he can extract and sell timber according to the rules of selective logging techniques. The PFAC strategy (*PfacStrat*) requires the agent to cultivate 4 ha of PFAC (see Scopel et al. 2013). The *Fm+Pfac* strategy aggregates the two previous ones: the agent has to cultivate PFAC and to manage his forest, in addition to the basic breeder activities. The last two scenarios simulate a strict compliance to environmental law: the agents do not touch their LRs: the *StandLR* agent performs his breeder standard activities on his authorised surface while the *PfacLR* agent is also obliged to cultivate 4 ha of PFAC. When a scenario is assigned to an agent, he is obliged to carry out the additional activities of this scenario, even if they are unsustainable for him. For example, in addition to his breeding activities, the agent with *PfacStrat* has to cultivate 4 ha of PFAC each year, even if he does not have enough resources for that. He is not allowed to change his assigned strategy during the runtime.

At the beginning of a simulation, the six agents are strictly identical, differing only in their strategy. Because the principle is to compare the results between the agents according to the scenarios, they cannot change their strategy during simulation and they do not interact.

4.2.3 Model description

Main principle

Many elements of the reality were not taken into account during the design process to keep the model as simple as possible.[(2)] In order to focus on the primary goal of the model, which is assessing land-use options, we kept only the entities and the operations related to the agricultural activities, thus omitting many other elements that are part of the daily life of the farmers (e.g. regular off-farm work, member aging, marriage, etc.). In this regard, the focus of our analysis is to better understand and assess the feasibility of each new activity with respect to the control scenario in terms of family labour management, availability of land, and economic profitability. These three elements are schematised in the flowchart of Figure II 4.1.

[(1)] BDI (for belief–desire–intention) is presently a common architecture for cognitive agents. Based on a practical human reasoning developed by M.E. Bratman (1987), it provides a deliberative mechanism for selecting concurrent plans, then executing the active ones.

[(2)] A full description of the model is available in Bommel et al. 2012.

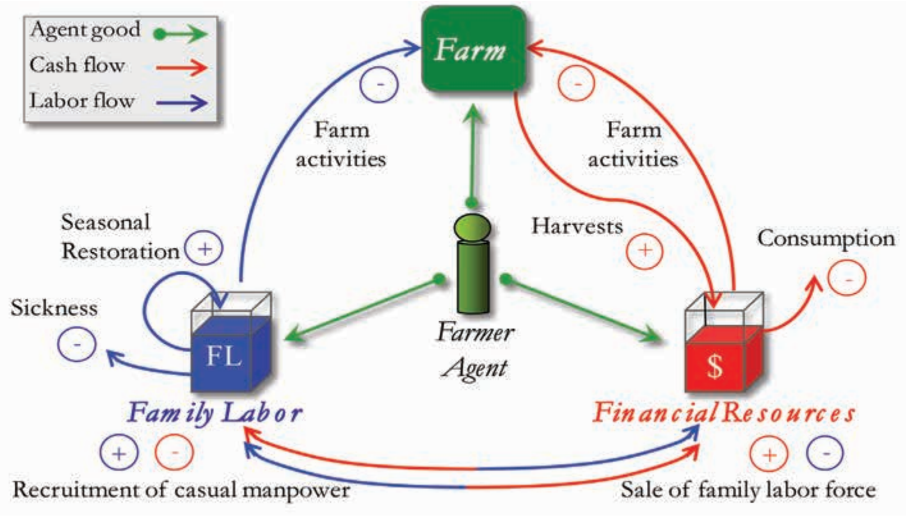

Figure II 4.1 Systemic diagram presenting the cash and workforce flows.

According to its structure, a family is endowed by a given quantity of labour (i.e. a given number of available working days per season). As any activity requires time, the stock of available working days decreases with addition of agricultural activities. Thus, an agent is constrained by his labour endowment. The agent is also constrained by the access to and disposal of financial resources. Therefore, to manage his farm, the agent owns two limited and interchangeable stocks: when he lacks labour force, he can hire temporary workers if he has financial resources, and conversely, when he needs money, he can sell a part of his available workforce as outside labourer days (without exceeding 90 days/season/worker). Available financial resources are systematically actualised according to the financial results of the preceding period.

Model structure and dynamics

The main elements of the model are grouped in two packages. The first contains the structure of the farm and the dynamics of its vegetation, and the second package contains the family, its labour force, financial resources, and farming activities.

A family is composed of children (0 to 4) and workers (2 to 4) with a landholding that encompasses 100 ha. Each plot (1 ha) is covered by forest, fallow, annual crops, or pasture. Annual crops (rice or corn) can be cultivated in a traditional way or using PFAC techniques. An unmaintained crop or pasture degrades progressively until it reaches a threshold where it becomes a fallow.

The technical and economic parameters (e.g. unitary prices and costs, labour demand by activity, and yield are available on the model web page, see footnote 2) have been set by looking at data from field surveys (Barbosa et al. 2008), experts' knowledge, and comparison of findings from other studies (de Reynal 1995, Vosti et al. 2002). The PFAC parameters have been obtained from data generated by the FloAgri project.

The simulations are run for 40 years. As the Amazon climate is clearly divided in rainy and dry seasons[3], the simulations are scheduled by an annual time step divided in two sub-steps with distinct seasonal farming practices. At the end of the year, each agent performs an annual balance to level the accounts and make specific purchases.

For each season, the land cover evolves naturally and the agent performs his seasonal activities as a sequence of three phases: spends money for the semester consumption; works on his land to produce agricultural goods; harvests and sells the production.

Vegetation dynamics

Each hectare of land cover evolves naturally with age and according to the activities carried out in the plot (Figure II 4.2). For example, an abandoned crop encroaches gradually (i.e. its abandonment level increases with each season) until, beyond a threshold, it turns fallow. After 30 years, a fallow turns to young forest, which requires 30 years more to provide harvestable trees (3 trees/ha). An unmanaged

[3] In the Pará state, the rainy season usually starts in December and stops in June, so the farmers plant their crops by the end of November. The dry season is from June to November, when the slash-and-burn activities occur (Moraes et al. 2005).

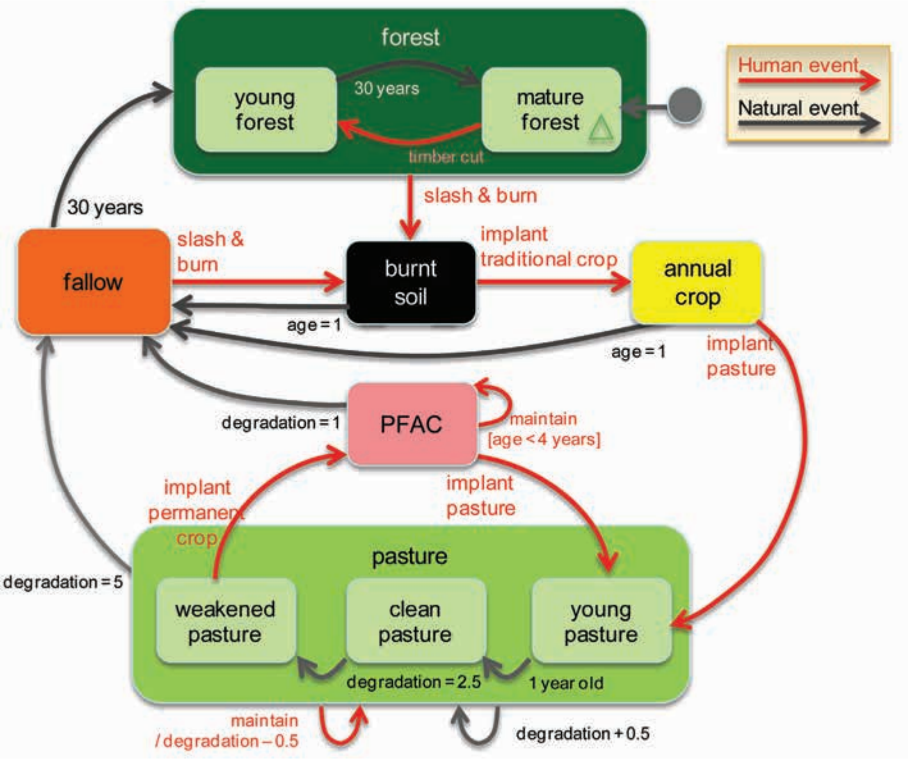

Figure II 4.2 The land cover state-transition diagram.

crop or pasture produces less than a managed one (15% drops per abandonment level):

$$\textit{actual production} = \textit{optimal production} \times \textit{neglected factor} \quad (1)$$

where: $\textit{optimal production} = \textit{production/ha done by the model data}$ and:
$\textit{neglected factor} = (1 - \textit{degradation loss factor})^{\textit{abandon level}} = (1 - 0.15)^{\textit{abandon level}}$

On any plot, the smallholder can suppress a cover and plant a new crop. To counteract the natural degradation of the crops, pastures, and cattle, some activities are required to maintain their productivity. The Figure II 4.2 shows all the vegetation types and the different ways (by natural transitions or by smallholders actions) through which land cover changes its state.

The cattle dynamic is very similar to the vegetation dynamic: when it is adult, a cow produces a quantity of meat per year, depending on the pasture quality and on its level of maintenance (see equation 1). In actual terms, this production matches a gain of body weight and the birth of a calf. But the model aggregates this production as a quantity of meat harvested and sold by the farmer. If the herd is neglected, it produces less and less and finally dies. Because all the cattle production (i.e. the calves) is sold, the farmer has to buy new cows during the annual balance stage in order to increase the size of the herd.

Farmer activities

After consumption expenses (cost: individual consumption × family size), the farmer performs his seasonal agricultural activities. Although breeding is a preferred investment, the agent dedicates a part of his labour force for self-consumption (only when his cash is lower than twice his consumption expenses): he cultivates half a hectare per family member of annual crops that will be harvested in the next season.

Then, the smallholder spends time and money on upkeep of the pastures and cattle. With the remaining cash and manpower, he performs an expansion loop, whose actions depend on each scenario. The expansion loop is constrained by forest or fallow availability, possibility to expand in case of constraint scenarios (*FmStrat*, *Fm+Pfac*, *StandLR*, *PfacLR*), and the availability of family resources.

At the end of a season, the remaining workforce is sold (max 90 days/worker). Here it should be noted that the sale of manpower might be unrealistic: in case of comfortable savings, smallholders would probably rather seek to improve their standard of living. Nonetheless, because we wanted to compare the results of each strategy on the same basis, we removed this option and the sale of extra manpower was kept for all agents without taking into account any limit of savings.

Farmer specific activity: FM on LR (*FmStrat and Fm+Pfac*)

The FM supplementary activity requires the agent to protect his LR (80%). But while performing the FM scenario, he is authorised to extract and sell timber (3 trees/ha or 16 m^3/ha) that is sold at BRL 54/m^3, or USD 27/m^3 (4). A company performs this activity and the charges are already deducted from the sale price. After having cut down the mature trees of one-third of the LR, the logged forest plot is protected during the next 30 years, meaning that the entire LR is logged for three years and then no timber harvest occurs during 27 years. Because farmers are authorised to slash and burn the forests located outside the LR to plant crops, timber extracted from this activity is also sold at 54 BRL/m^3, or USD 27/m^3. In contrast, agents who do not perform FM sell their trees as uncertified wood at BRL 27/m^3, or USD 13.50/m^3.

Farmer-specific activity: permanent field of annual crop (*PfacStrat, Fm+Pfac and PfacLR*)

The supplementary activity PFAC requires the agent to cultivate 4 ha of permanent crops. Normally, PFAC allows recovering degraded pastures by using no-till techniques. But if there is no degraded pasture around the house (500 m), the agent looks for an old pasture still producing, close to the house.

In order to remain homogeneous with the other crop management, the modelled activities of PFAC consist in planting crops, upkeep, and harvesting. In reality, a farmer harvests his PFAC main crops (½ ha of rice and ½ ha of corn) at the end of the wet season and then sows a leguminous cover crop to control soil erosion and weeds, increase organic matter and water in the soil, and fix nitrogen. So, in a one-year cycle, both crops are produced. In the model, we consider one harvest per season that aggregates both crops (main and cover crop) into one (production: 1425 kg/ha/season and price: BRL 0.835/kg, or USD 0.418/kg).

To maintain the PFAC, the farmer has to buy fertilizer (BRL 357/ha, USD 178.50/ha), urea (BRL 80/ha, USD 40/ha), and herbicides (BRL 310/ha, USD 155/ha), considering that the seeds have been stocked from the previous harvest. Thus, the agent spends an average of BRL 373.5/ha/season (USD 186.75/ha/season) for keeping up the PFAC. To plant it, the agent buys limestone (BRL 420/ha, USD 210/ha) and phosphate (BRL 400/ha, USD 200/ha), plus the maintenance products (1193.50/ha, USD 596.75/ha).

The PFAC has a lifetime of four years. During its last season, the cover vegetation sown is pasture that will be productive in the next season.

In interviews, farmers involved in the project have recognised PFAC as greatly advantageous. They explained that they earn in comfort by working near their homes. This aspect is, however, not taken into account into the model.

4.2.4 Main principles of simulation

Each farmer owns a single lot of 100 ha and he is not allowed to move to another farm or to expand by buying new land. Each lot has a similar vegetation cover. The agents vary only in their specific activities (FM, PFAC, and/or LR compliance). For standard simulations(5), each family has three workers and three children. It starts with BRL 7200, equal to USD 3600, (members × initial cash/person = 6 × BRL 1200 (USD 600) and 468 available workdays (workers × work days per season = 3 × 156). In its standard version, the model is deterministic: no randomness is involved during the simulations. Thus, from a given initial state, it will always produce the same output for each strategy(6).

Starting from the same state, the land cover at the end of a simulation (40 years) is quite different depending on the performed scenario. After 12 years (Figure II 4.3 bottom), the conventional breeder (*StandStrat*), for example, has converted all his land into pasture (this period is called the installation phase). In contrast, the agents in charge of FM as well as the agents who are artificially obliged to respect the law, have maintained their LR (80 ha). Their installation phase is much shorter (five years).

By looking at the agents' incomes, as noted previously, the output data cannot be rigorously compared with real incomes since the agents keep their standard of living, whatever their savings. What is more relevant is to compare the economic results among the agents in order to rank the income levels according to the scenarios.

(4) Exchange rate is about 1 BRL (Brazilian real) = USD 0.50.

(5) The model has been implemented on Cormas, an ABM software dedicated to resources management (http://cormas.cirad.fr).

(6) A stochastic version (with randomness) will be used in the analysis in order to test the impact of sickness probability or when specifying a new initial land cover (see 4.3.3 and 4.3.4).

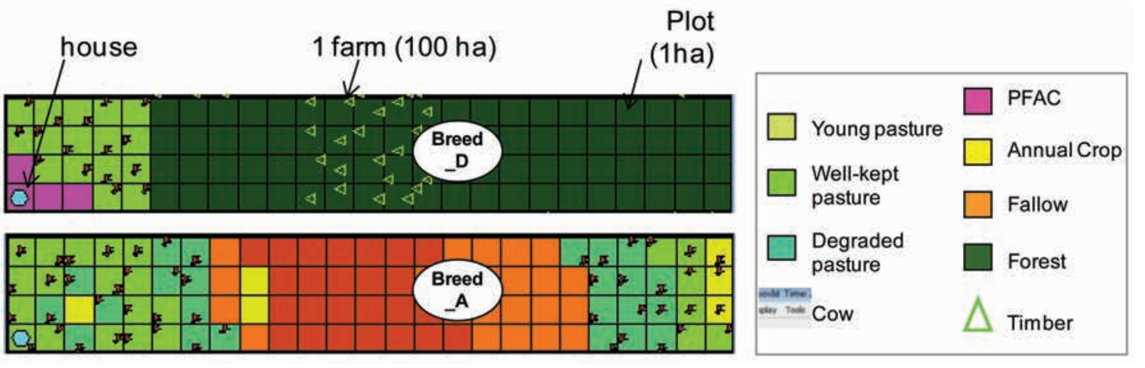

Figure II 4.3 Example of land cover for a standard simulation for two different farms after 20 years.

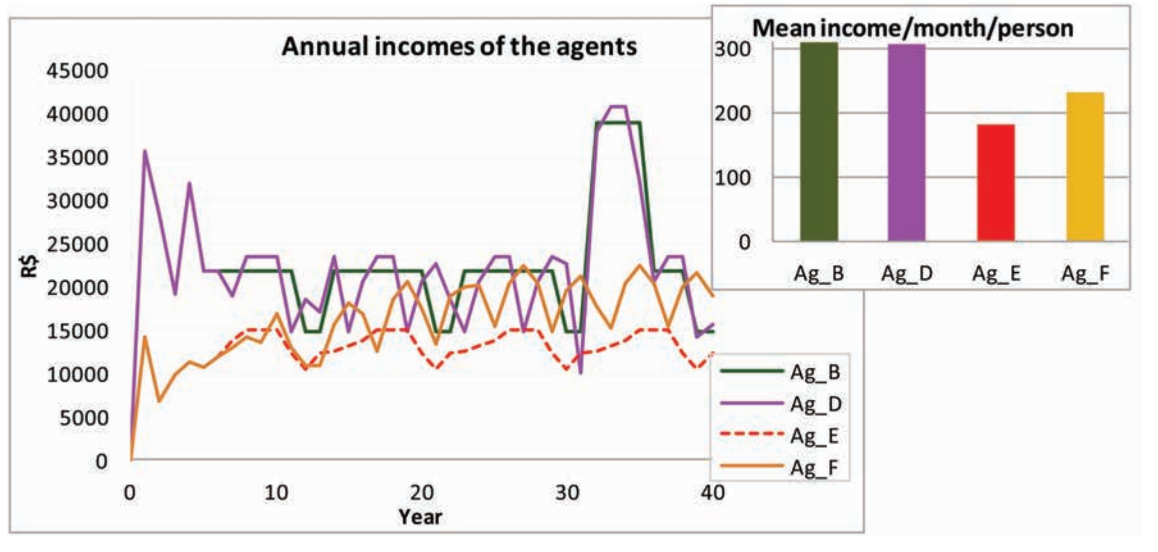

Figure II 4.4 Evolution of the annual incomes of four agents respecting their LRs, during a standard simulation of 40 years.

4.3 Scenarios results

4.3.1 The impacts of FM and PFAC for agents respecting their LR

Given the fact that the *FmStrat*, *Fm+Pfac*, *StandLR,* and *PfacLR* agents respect their LRs, the efficiencies are compared on the same area available for cultivation (20 ha) (Figure II 4.4). Indeed, at the end of the third year, each agent has deforested his authorised surface. The rest remains forest and only the *FmStrat* and *Fm+Pfac* agents can use it to harvest timber during the FM cycles.

The standard breeder obliged to preserve his LR (*StandLR*) without any alternative activity has an average income of BRL13 000/year for a six-member family, meaning BRL 361/month (USD 180/month) per worker, calculated from year 10 to 40, i.e. after the installation phase; this is a quarter below the minimum salary (the Brazilian minimum salary in 2009 was BRL 465/month, or USD 232.50/month, see Portalbrasil, 2009). During the first five years, the family income originates mainly from production of annual crops and timber sales while converting forest into pasture. During this installation phase, the smallholder invests intensively in livestock by buying cows and planting new pastures. When the authorised 20 ha are fully covered with pasture and because the smallholder cannot buy new land, he manages his herd and sells out the remaining available working days of the household. The regular fluctuations in livestock income are due to the sale of the cull cows and the purchase of heifer calves.

FM significantly increases the incomes of *FmStrat* and *Fm+Pfac* agents every 30 years (the duration of the forest rotation cycle). The first growth peak is smaller than the second one because the agents invest in livestock: while planting new pastures and buying many cows, they transfer a high part of the first FM profits into livestock capital. Accumulated cash income over 40 years for these two scenarios is about BRL 907 000 (USD 453 500), or

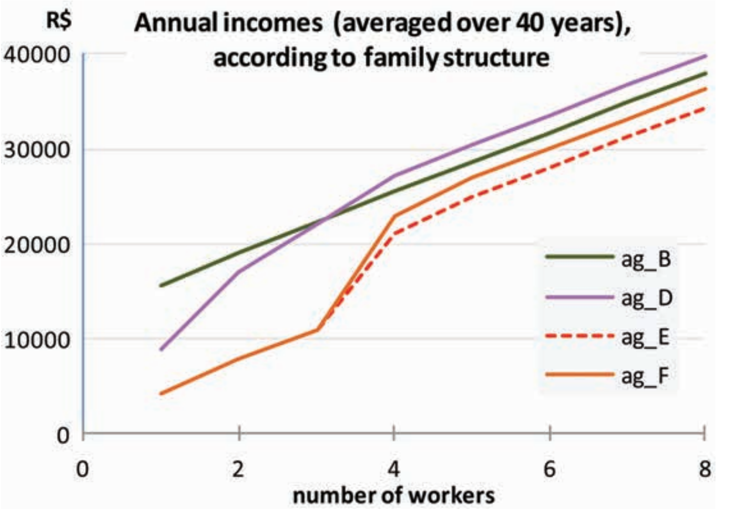

Figure II 4.5 Annual incomes of the agents according to the number of workers.

55% higher than for the breeder obliged to preserve his LR without FM.

Between the timber harvesting periods, incomes for *FmStrat* and *Fm+Pfac* agents drop to a value close to that of the *StandLR agent*. Nevertheless, even during this forest regeneration phase, FM has a positive effect: mean income during the renewal phase is approximately BRL 1090 (USD 545)/month for *StandLR*, while it reaches BRL 1670 (USD 825)/ month for *FmStrat* and *Fm+Pfac*, which is 52% better. Such difference is linked with livestock and pasture quality: short of savings, the *StandLR* agent does not succeed in maintaining all the pastures and the cattle, which gradually become less productive (equation 1). Thus, the mean monthly income from livestock for the *StandLR agent* is BRL 344 (USD 172) while it is more than twice as high for the *FmStrat agent*: BRL 797 (USD 398.5). In this scenario, FM income provides some financial resources that allow the farmer to maintain the productivity of livestock and pasture.

The starting phase (first 10 years) for the *PfacLR* agent is as difficult as that of the *StandLR agent*. But, by adopting permanent crops, this agent succeeds in gradually recovering the degraded pastures and thus is able to reach higher cattle productivity. This agent also increases household income by harvesting his permanent crops. As PFAC requires more labour for planting and maintenance, the agent sells fewer working days. Nevertheless, after 12 years, the annual income becomes higher than that of the *StandLR* agent, and it is equivalent to agents involved in *FmStrat* and *Fm+Pfac* after 20 years. At midterm (15 years), PFAC provides positive effects on family income.

The diagram in Figure II 4.5 shows the annual incomes of the agents according to family structure. The same former simulations have been run but here for a family of eight members, with successively one to eight workers.

Not surprisingly, whatever the agent strategy, annual income increases as the family has more workers. This increase is mostly due to the higher number of working days available to be sold. However, for the breeders who do not perform FM (*StandLR* and *PfacLR* agents), an income shift is observed when there are more than four workers: above this number, the family is able to maintain and clean up all its pastures, thus the difference in annual income with agents performing FM is low and solely due to the timber harvest peaks. Below four workers, the family lacks the labour force to maintain all its crops and pastures, which causes a decrease in productivity. We can thus conclude that, when subcontracted, FM is mainly useful for families with few workers since it helps to compensate for the lack of manpower.

4.3.2 The cost of staying legal

This section assesses the cost of staying legal by preserving the LRs. As stated in the Forest Code, the law requires landowners in the Amazon to conserve 50% to 80% of their farmland in forest. The following simulations compare agents that respect their LRs (*FmStrat*, *Fm+Pfac*, and *StandLR* agents) with those who do not (*StandStrat* and *PfacStrat*). Figure II 4.6 shows the evolution of the agents' annual income. The installation phase (time to cut the forest) is much longer for *StandStrat* and *PfacStrat* agents – 12 years – compared to the five years for *FmStrat* and *Fm+Pfac* agents (and also for *StandLR* and *PfacLR agents*). During this phase, they face

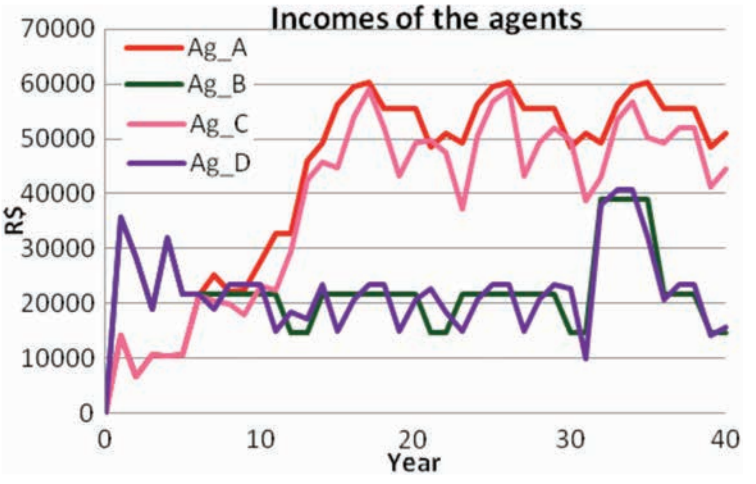

Figure II 4.6 Evolution of annual incomes during a standard simulation of 40 years, according to four agent types.

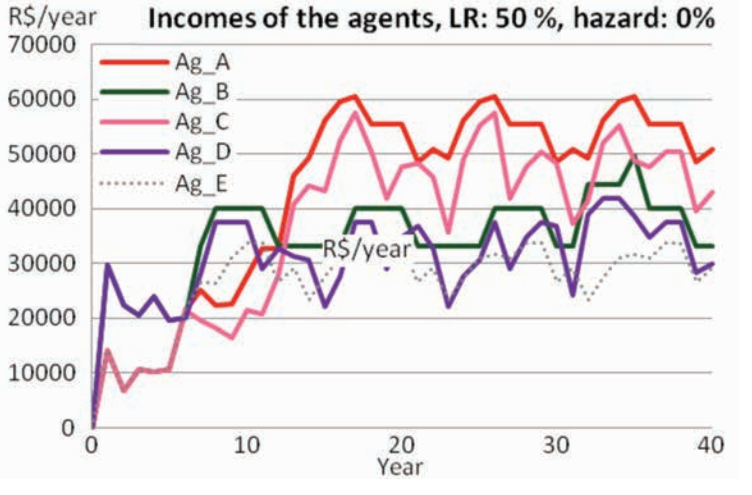

Figure II 4.7 The annual income of the agents when LR is set to 50%.

low income (short farm production and investment in livestock). But after this period, when they have completely turned their farm into pasture, *StandStrat* and *PfacStrat* agents succeed in increasing their savings more rapidly than the other agents who kept their LRs. Such a shift is linked with the livestock income on 100 ha instead of 20 ha and the fact that not much manpower is required for its maintenance (300 working days/year for 100 ha of pastures with cattle).

Once the standard breeder converts the 100 ha of his land to pastures, his activity consists mainly in managing his herd and selling the extra labour force. For these specific simulations, FM does not compensate the breeding loss due to pasture limitation. Excluding the installation phase, the monthly income of the *StandStrat* agent is about BRL 4250 (USD 2125), whereas it is only BRL 1670 (USD 835) for a breeder doing FM, i.e. 60% lower. Such results give an idea of the opportunity cost for smallholders to conserve the LRs even when FM is possible.

The *PfacStrat* agent has results similar to that of the *StandStrat* agent. Since he needs more manpower to plant and maintain PFAC, his income is a little lower than that of the *StandStrat* agent. Unlike the *PfacLR* agent on 20 ha (Figure II 4.4), PFAC has no positive effect when using the 100 ha, even after a long period.

The Brazilian Forestry Code allows, in certain zones (consolidated zones, defined by the ZEE plan: the state of Pará delineated its territory in Ecological-Economic Zones), to use and deforest up to 50% of the farm (Figure II 4.7).

Obviously, this modification of LR does not affect *StandStrat* and *PfacStrat* agents because they ignore these constraints. But for the agents that keep their LRs, this change of the LR ratio increases their monthly incomes: from BRL 1090 to 2500 (USD

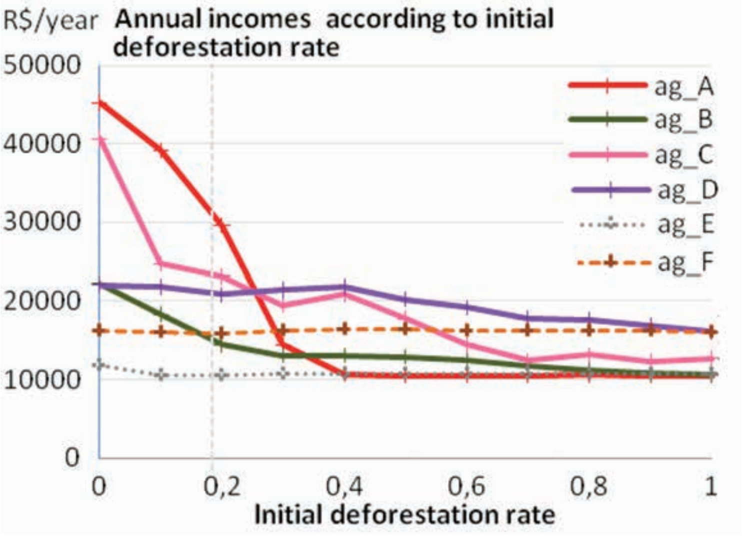

Figure II 4.8 Mean annual incomes according to initial deforestation.

545 to 1250) for *StandLR* (+130%); BRL 3035, or USD 1517.50 (+81%) for *FmStrat*; and BRL 2680, or USD 1340 (+74%) for *Fm+Pfac*. Compared to the *StandLR* agent obliged to protect his LR, the FM has a lower impact on income, except for the first years of installation.

Thus, economically speaking, a reduction of LR to 50% would help small farmers more than applying FM on 80 ha. On the other hand, if LR were complied with (which is seldom the case), it would decrease the forest size from 80% to 50%.

4.3.3 Portion of property initially deforested

To ensure a good understanding of the model, it is also necessary to begin the simulations from initial states with less virgin forest, as is presently the case for a majority of smallholders in Pará. Modifying the initial deforestation part, from 0% to 100%, has resulted in the following output. For each new initial state of the farms, deforested plots are randomly covered by an annual crop, pasture, or fallow, with a random degradation level. In the cases where the deforestation is greater than the authorised portion (20%), the agents that respect the law (FM and LR strategies) will not use a part of their land (covered by fallows and old crops) so that forests can regenerate. But because forest regeneration is a very slow process, the simulations show that full restoration of the LR comes after a long period (about 38 years according to the initial degradation level). In that case, the agents undertaking FM can harvest timber even if their forests are below 80 ha (which is something that is not authorised in practice). For each value of the initial deforestation portion parameter, 100 simulations are repeated in order to normalise the effect of the randomness (Figure II 4.8).

The analysis shows that the incomes of the *StandStrat* and *PfacStrat* agents, who do not respect the LR constraints, decrease rapidly with the initial degradation rate. This is because the farmer spends time and money to maintain degraded pastures that are basically unprofitable due to their poor productivity (the "initial deforested" parameter requires that a portion of the land cover is degraded, so equation (1) gives a lower production). Since the beginning of the settlement is very sensitive, losing time and money for land recuperation during the first stage holds back the development of the agents. When 40% of the farm is deforested, the standard breeder has the same income as the *StandLR* agent, i.e. he is mainly a farm labourer.

For the *FmStrat* agent, who is spending energy to maintain unprofitable pastures on 20 ha, the lack of preserved forest also reduces the FM profits and has a more negative effect on income compared with the *Fm+Pfac* and *PfacLR* scenarios.

The signatures of the agents doing PFAC (*PfacStrat*, *Fm+Pfac*, *PfacLR*) are dissimilar: *Fm+Pfac* and *PfacLR* agents that work on 20 ha are not affected by the initially deforested parameter. Because they do not spend much on livestock, they are able to recover their degraded pastures and manage a small area whatever the initial degradation level. *Fm+Pfac* provides the best income when initial deforestation is higher than 25%. On the opposite end, *PfacStrat* has low resistance to initial degradation, mainly for low deforestation rate. This is because the agent spends a lot of energy to plant permanent crops while investing at the same time in livestock and expanding

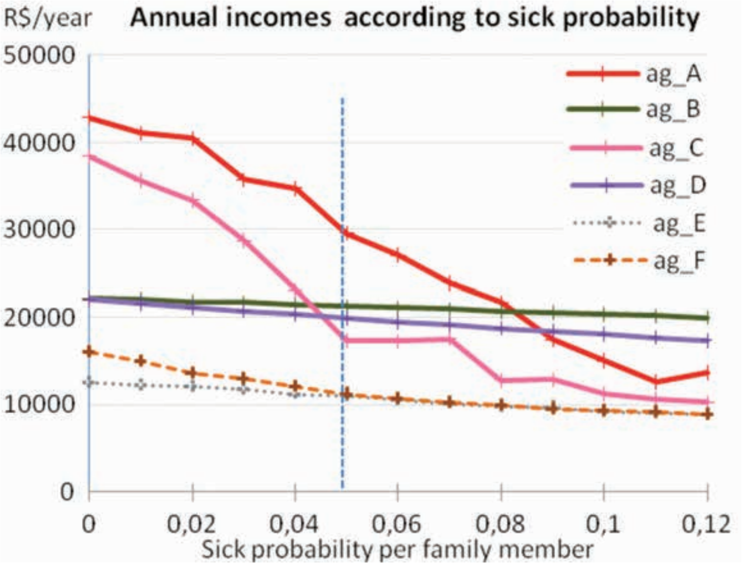

Figure II 4.9 Annual incomes of the agents according to sick probability per member; 0.05 is the standard risk from literature.

in the forest. So, when starting from degraded land, PFCA presents positive effects but solely when the farmer does not invest heavily in livestock at the same time. Depending on the degraded surface, the period to get PFAC positive effects can be long. By comparing, for example, the dynamics of *StandStrat* and *PfacStrat* from a 20% degraded farm, the mean income of *StandStrat* over the 40 years' simulation is higher than of *PfacStrat*. But *PfacStrat* has much better incomes only after a long period (20 years, not visible in Figure II 4.8).

4.3.4 FM, PFAC, and resilience

Analysing the effect of hazard (sickness and accident) on smallholders is important since the family workforce plays a key role in household strategies. For the previous analysis, the sickness probability was set to zero, but the available statistics show that, in Amazonian pioneer fronts, hazard is greater and the risk of becoming seriously ill or being injured is higher than elsewhere in Brazil. According to IBGE (2008) estimates a person stays in a hospital once every 10 years (5%/season/person).

For the current analysis, the sickness option has been activated. In the next graph, Figure II 4.9, the sickness probability has been tested from 0% to 12% per season (analysing upper probability is not useful since the available labour force is almost zero). For each season, every member of the family has a random chance to be sick and unable to work during this time. Due to stochastic events, the simulations are repeated 100 times for each parameter new value.

Obviously, all the agents lose income to the extent that hazard risks increase. Interestingly, *StandStrat* and *PfacStrat* agents who do not respect their LRs are more sensitive to hazard. They can hardly expand and maintain their pastures and cattle when they lose manpower. In contrast, agents managing their forests (*FmStrat* and *Fm+Pfac*) tend to be more resistant to hazards because of the extra revenues coming from FM that make them much less affected by a temporary loss of labour. As the PFAC strategy requires additional investments in money and manpower, *PfacStrat* and *PfacLR* are more sensitive to hazards. FM compensates this sensitivity in the case of the *Fm+Pfac* agent. So, these results confirm the previous ones (Figure II 4.5): when subcontracted, FM helps to compensate for the lack of manpower.

Figure II 4.10 shows the distribution of incomes when hazard probability is set to its standard value (5%/ season/person). In addition, it compares the effect of the LR authorised level for the two scenarios – 80% and 50%.

The bar chart (right) presents the average income over the 100 simulations of each agent. The *StandStrat*, $FmStrat_{LR:\,50\%}$ and $Fm{+}Pfac_{LR:\,50\%}$ agents have similar mean incomes (about BRL 30 000/year, or USD 15 000/year). But the standard deviations are quite different: *StandStrat* shows irregular incomes while *FmStrat* and *Fm+Pfac* are much more regular. This irregularity of incomes is more visible on the left chart: here, each point is the annual income of an agent for one simulation. By sorting these values for 100 simulations, the curves show how these incomes are distributed. For standard breeders exploiting 100 ha, the chances to succeed are spread from highest to lowest incomes (high variance): in more than 20% of the simulations, the *StandStrat* agent fails to manage his farm. When an accident or a disease

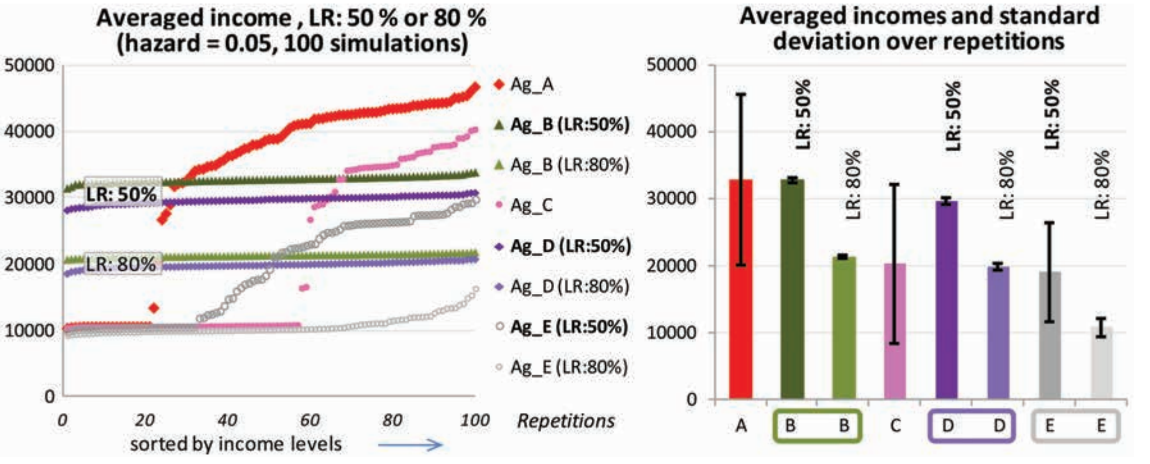

Figure II 4.10 Annual incomes when LR is set to 50% or 80%, with 5% risk probability; sorted distribution of incomes for each simulation (left chart); average incomes over 100 simulations and standard deviation (right chart).

occurs in the installation phase, the consequences strongly impact this agent's economic situation and his farm's productivity. This agent is more able to resist hazards when his expansion phase is complete. These results are worst for the *PfacStrat* agent, who fails in 60% of the cases: this agent is more sensitive to hazard during the installation phase. As PFAC requires investments, it is only profitable in the long term when the family is strongly installed.

In contrast, *FmStrat* and *Fm+Pfac* agents, who manage their forests, have very stable incomes. Even when a family member is unable to work, the quality of the farm production is such that the family can better resist a temporarily lower labour force. When the LR is set to 50 ha, the mean income is equal to that of *StandStrat*, but with low fluctuations (over 100 repetitions) and, above all, with 50 ha of preserved forest.

4.4 Discussion: Optimal conditions versus hazard and degraded lands

As stated by Popper (1963) for theories, a model cannot be validated in the sense of having complete confidence on its outputs. Like theories, a simulation model is inherently wrong (Bradbury 2002): sometimes it can be corroborated by data but in most cases, it is refuted by empirical observations. So, we consider that comparing the model outputs with data does not permit a conclusion that it is undoubtedly valid; the data comparison is just a way to increase the likelihood of its results. Furthermore, since the alternative practices developed in the FloAgri project are recent and not broadly used in the Amazon, it is also hard to compare the model outputs with real data. But while the lack of historical data prevents us from "validating" the model, its dynamics are coherent with observations and expert knowledge. Instead of comparing static data on each practice independently (performing a cost/production comparison is quite simple), the ABM helps demonstrate how various activities can interact. It helps explain why, depending on the context, some practices can either be efficient or fail. Of course, it would be interesting to compare our results with an optimisation model that aims to determine the best mixture of land-use patterns. Nevertheless, it should be emphasised that our ABM does not seek to optimise land-use distribution. Since it focuses on the behaviour of agents in a temporal dimension, it helps us understand the reasons for success or failure of a strategy in various situations.

Our results show that without any agricultural alternative, a small breeder compliant with LR has low income that comes mainly from the sale of his labour force. A change from 80% to 50% of LR would obviously increase his cash income (+130%) more than investing in FM of his LR (+52%, without hazard).

The model shows that FM and PFAC are not miraculous solutions that allow a smallholder to prosper while preserving his LR. Compared to a standard breeder artificially restricted on 20 ha (*StandLR*), the adoption of alternative practices like FM can increase his income (twice his standard income in the best case). But what he earns from 20 ha of crops and pastures, plus the revenue he obtains occasionally from FM, remains lower than the income he gets from 100 ha of pasture. However, in that case, the conventional breeder has deforested all of his land and he is illegal with respect to the Forest Code. In recent years, the controls have become more frequent and the sanctions have been tightened to such an extent that farmers can no longer break the law as they did before.

The additional practices, however, may have positive effects when various types of hazard are introduced in the model. For example, the standard breeders are more sensible to sick probability than the agents performing FM. As the risk of being seriously sick or wounded is high in the Amazon, FM increases the resilience to hazards. The additional revenue generated by FM appears useful when the labour force is reduced because it helps with investments in productive livestock, which does not require a lot of work.

PFAC has positive effects when a reasonable part of the farm is degraded. By using no-till techniques, it allows recovering some productive pastures when the standard breeder can just maintain poorly profitable cattle. But PFAC is a risky activity because no-till farming needs competences, manpower, and financial investment. The model shows that PFAC weakens farmers when they are in the installation phase: they cannot invest in such techniques and livestock at once. By gradually recovering degraded pastures, PFAC can be seen as an intensification practice that improves cattle productivity over the long term.

As a result, when starting from a degraded farm and when taking into account hazard probabilities, the FM may offer equivalent mean income to that of an unrestricted standard breeder, but with higher stability. Finally, coupling FM and PFAC seems to be an interesting alternative that might make the farmers more resistant to hazards and provide higher income, while at the same time preserving the major part of their forests.

4.5 Conclusions

By implementing agricultural activities related to standard or specific strategies, an ABM offers the advantage of explaining how several actions can complement or compete. In contrast, a simple comparison of static economic returns between different activities does not inform about such complementarities. By targeting the model on the management of the labour force, the simulations allow us to explain how some actions may affect the achievement of others. Thus, our ABM helps to explain why some alternative practices can either be efficient or fail, depending on the context.

As several studies have already pointed out, succeeding in making a small-scale FM plan financially viable in the Amazon region remains a challenge and many barriers have yet to be removed (Hajjar et al. 2011, Drigo et al. 2013). It is considered relatively risky in the short term to invest in FM, whereas investing in cattle is often considered to be a safety option, at least in the short term. The latter situation may reverse in the long term, but only with stronger efforts to decrease the many barriers threatening the long-term viability of FM (see Part II, chapter 3, or Drigo et al. 2013).

However, standard breeding, which is the most common production system among smallholders in the Amazon, is also risky during the installation phase (Tourrand 2009). When taking into account the current available cash and manpower of a family, our ABM shows that a breeder quickly meets difficulties that prevent him from developing his operations as he would under optimal conditions. The model reveals that the agents that prefer to pursue ranching activities by converting all their land to pasture are economically vulnerable at the beginning and they can easily fail due to increasing risk and land degradation.

In contrast, the agents who are able to manage their forests tend to strengthen their resilience capacities against hazards, mainly when considering the sickness probability. Indeed, when subcontracted, the FM cannot improve the mean annual income of smallholders much in the Amazon, but it tends to stabilise the income and improves household resilience in the long term by helping to maintain good productivity from pastures and livestock on a reduced area.

Adding PFAC increases potential benefit for families to invest in FM, underlying potentially interesting complementarities. When few pastures are degraded, PFAC improves cattle productivity over the long term. Nonetheless, as PFAC is an intensification technique, it cannot be performed while investing in livestock.

Since controls and sanctions have been strengthened in recent years in the Brazilian Amazon, it is no longer viable to be illegal with respect to the Forest Code. But, without any agricultural alternative, a small breeder compliant with the Forest Code would have very low income, earning a living by selling his labour. In that situation, an investment in efficient FM could double the revenue. A change from 80% to 50% of LR would obviously increase his income. Thus, despite the precautions required in any modelling, our results allow us to conclude that FM associated with intensification practices such as PFAC may allow smallholders to achieve incomes equal to those of extensive ranching over all landholdings. Furthermore this production system is less sensible to hazards while it preserves the forest.

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