An ABM to monitor landscape dynamics and to undertake collective foresight investigations in the Amazon

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Abstract

By seeking for alternative land uses in the Amazon, we designed an Agent-Based Model (ABM) containing a set of rural practices for small-scale farmers. In order to reach a more sustainable development, we analyze the benefits and the constraints of these practices.

By comparing various production activities starting from the same initial conditions, we test several strategies and their efficiency faced to different initial conditions and environmental laws.

Our study does not compare solely the financial profits of the agricultural activities. But it seeks to better understand and assess the feasibility of new activities in terms of family labor management, availability of land and economic profitability.

Our first results conclude that a strict compliance with the law is not economically sustainable if the farmers still apply their standard land use strategies.

We hope that this model could become a useful tool for the small farmers. By easily modifying the behavior of an agent, they could virtually invent and assess the efficiency of new practices on their farm. We also hope that this tool could become a means to facilitate dialogue between different stakeholders in the Amazon, in order to achieve more sustainable development.

Another model on Amazonian deforestation, what for?

As an overview of models dealing with tropical deforestation, (Kaimowitz and Angelsen, 1998), (Angelsen and Kaimowitz, 1999) explain that actually most models are static and tackle deforestation at the macroscopic scale, up to represent a whole region as the Amazon basin. These econometric or geographical models are based on the identification of correlations between macroeconomic data (e.g. GDP, taxation, production costs, national or international demand), as well as on the territorial structure

adfa, p. 1, 2011.

(e.g. roads, urban and agro-industrial centers) and land use (e.g. forest, crops). From a set of univariate or multivariate observations of past trends, the modeler calculates correlations that are extrapolated. For example, based on correlations between roads and deforestation, (Nepstad D. et al., 2002) and (Laurance W. F. et al., 2001) make projections of deforestation according to the probabilities of creation of roads or of the paving of carriageways. Piketty (Piketty, 2003) notes that the presence of roads (and other infrastructure), is important, but is not the only factor explaining deforestation. These correlations are not constant over time and evolve according to technical and organizational innovations. Moreover, a simple correlation between the presence of a road and a deforested area is interpreted as a causal link of the road on deforestation. But it often happens that the roads are endogenous, that is they may have been built in response to previous deforestation.

For the majority of these models, the actors are not presented at these macro scales, or at best, in the form of density and population flows. In fact, knowledge on the determinants of deforestation is still rudimentary. These correlation models give a partial lighting on pioneer processes, without any explanation (Lambin, 1994). Yet they influence the international debate on how to preserve the Amazon rainforest (Poccard-Chapuis et al., 2005).

ABMs facilitate the understanding of involved dynamics, point out the multiple effects of options for action, and help to avoid unwanted feedback. It helps to assess human-environment interactions, feedback process and complex adaptive systems. As very few ABMs have been developed in Amazonia, this paper is a new step to better understand the underlying processes on land use in the Amazon region.

Pattern of cognitive decision versus activities designed from the observations of rural practices?

Most ABMs that address the simulation in social science, use intelligent agents whose rational behavior is based on the BDI (belief–desire–intention) architecture. This BDI model aims to solve the problem of planning (Bratman et al., 1988). Based on rational attitudes, it provides a mechanism for selecting concurrent plans then for executing the chosen plan. Thus, a BDI agent is able to deliberate about its future activities and their organization.

During a debate on the simulation in social sciences (Von Randow, 2003), two views competed: one, defended by the "social physicians", prefers to address the modeling in social sciences with simple agents, comparable to particles. In agreement with the position of sociologists, the other view recommends using cognitive agents to generate social dynamics. When the formers wonder why do complicated agents when you can do simple, the latter defend the idea that human thought is far more complex and that the men who constitute a society cannot be considered as particles. They see the power of today's computers as a mean to design realistic models.

On the contrary, (Deffuant et al., 2003) explain that complicated models are not necessarily more realistic than simple models. They argue that the BDI architectures, often used to model cognitive agents, do not necessarily rely on robust scientific basis and do not derived from the precepts of neuroscience nor psychology nor philosophy. Similarly, architectures based on symbol manipulation do not inherit from advances in linguistics. They conclude that the design of complicated models is much easier than establishing robust results on emergent properties.

Of course, overly simple models on social science cannot be applied to real situations, without special care. But this remark is also valid for more complicated models. The more a model is complicated, the more likely to get simulation bias. Given the high sensitivity of ABMs, the chances of getting results that come from artifacts may increase rapidly with the model complexity.

Furthermore, in the first step, our question is not to simulate the human intelligence, but rather to describe, synthesize and formulize observed rural practices in order to understand their environmental and economical impacts on the long term. For the next step, we want the farmers to design themselves new practices and virtually test them by simulation.

Model description

The purpose of the *Amaz* model is to assess scenarios associated with the integration of Crop-Livestock-Forest in the pioneer fronts in the Amazon. The different scenarios allow comparing different strategies of land use and the consequences in terms of Environmental Services and the family incomes. The indicators of comparison aim at weigh up the different ways to (1) reduce the environmental impacts of agricultural activities; (2) preserve riparian forests and legal reserves; (3) restore degraded areas, creating conditions for new production and decreasing the need for deforestation of new areas; and (4) creating jobs, income, and better conditions to family farms.

An Agent-Based Model to generate scenarios at the level of the farm

Designed to operate at the farm level, the goal of *Amaz* is to evaluate the consequences of various forms of land use. From a given initial state, the producers apply their agricultural practices, leading to different forms of landscape. By designing different practices (standard and new practices designed in the Amaz project), we compare various land use strategies.

Focusing on the actors, an ABM seems to be a thoughtful tool to reveal some key factors on deforestation. But, this also requires a presence on the field and numerous meetings with small-scale farmers to understand the organization of their work, their history and their social networks. The idea is to better understand the difficulties they have to face and imagine with them alternative practices of management.

What scenarios?

We define four scenarios to be compared:

1. Business as usual
2. Respect the law
3. Maximize the provision of environmental services
4. Maximize the production by intensification.

These scenarios are compared by applying them in four land use strategies corresponding to four types of actors. Each type prefers a management pattern as follows:

a. Prioritize livestock
b. Prioritize perennial crops
c. Prioritize agriculture
d. Diversification[1]

A scenario is designed as a set of modules inserted into basic activities and that will affect the practices. These ***modules*** are:

1. Conservation agriculture (no tillage)
2. Intensification of livestock (pasture and herd)
3. Sustainable forest management
4. Avoid deforestation (even if not below the authorized clearing rate)
5. Agro-forestry
6. Set-aside land (bare fallow for soil regeneration)
7. Stop the use of fire to clean the pasture.
8. Accelerated recovery of environmental liability
9. sylvo-pastoralism

[1] The Diversification strategy is to make annual rotations on priorities: year 1 = tree crop farmer, year 2 = cultivator, year 3 = breeder, etc.

Scenarios 0 are a set of "control" scenarios. For those, there is neither legal restriction, nor payment for Environmental Services.

Scenarios 1, "Respect the law". It starts with the calculation of environmental liabilities and set up a recovery plan (30 years to recover the liability) based on the module 6 (bare fallow) when above the limit of the legal reserve (LR) and when the “Area of Permanent Protection” (APP) is affected. If below the limit, the agent can deforest without exceeding 50% of deforestation, and without clearing the APPs. Implementation of module 7: the agent stops the use of fire to clear its pastures, but it authorized to slash and burn out of the legal reserve.

Scenarios 2: "Maximize the environmental services"

Based on extra modules n° 2, 3, 4, 5, 7 and 8, the principle is to accelerate the recovery of environmental liability, and to intensify the environmental services in order to receive compensations for these services.

Scenarios 3: "Maximize the intensification of production"

Based on extra modules n° 1, 2, 5 and 7, this set of scenarios aims at testing new practices like the intensification of livestock production or the conservation agriculture (no tillage).

Scenarios 2 and 3 are not yet implemented.

Principle of simulation

The principle of *Amaz* model is to cross two dynamics: the natural evolution of the vegetation (and soil) over time, and the activities of the producer managing its farm. Thus, depending on the initial state and the producer practices, the system evolves in a direction that can be measured by ecological and economic indicators. For example, we measure the area of forest or its fragmentation, the biodiversity and the biomass (Carbon), but also the family's income, the number of days worked out, amount of hired labor, ... Because the model is spatialized, we can also observe the evolution of the farm’s landscape over the simulated time.

Model description

First entry by the land tenure and the land use

In the Amazon, few farms are exclusively dedicated to livestock. Although the pasture productivity is good during the first 2-3 years, a farmer prefers, in most cases, grow a subsistence production on fresh slashed and burnt plots: this ensures his food security and the income will cover the implementation cost of the pasture. Even for ranching, farming subsistence is the initial step before the pasture. Furthermore, the most practiced technique to recover an old pasture is to turn it into food crops during one or two seasons, thus providing complementary animal fodder. Finally, the contraction of forest plots in old properties, as well as the compliance to environmental law oblige some farmers to reduce deforestation by intensifying their land use with a crop-pasture cycle. They also seek to expand their farm by buying new fields in order to remain under the legal threshold of deforestation.

Second entry by the workforce

The availability of the family labor is a key element of success or failure of the settlement on the front. (Tourrand et al., 2004) show that a family of 3-4 workers (a couple with two teenagers) has more chance to succeed than a couple with two young children. A disease or an accident that invalidates a person for several weeks has more impact for a family with few workers. In addition, some activities (slash, movement of the herd, harvest...) require two or three persons. Finally, the sale of a portion of its workforce facilitates family life. Thus, successful settlements on the pioneer fronts are often due to large families.

Structure of the model

Amaz is structured in two parts corresponding to the previous paragraphs. The Land package represents the spatial organization of the land. Situated along a side road, a 100 ha lot of colonization is divided into 400 m^2 plots. Each plot is assigned with a soil type, a slope and a land cover: forest, fallow, annual or tree crop, or pasture.

The herd is distributed on the pastures with a mean value of one livestock unit per hectare (in the version without intensification). Each cover has technical and economical attributes, its own dynamics, several requirements linked to its manpower needs and farm inputs, and a production value. Each season, it generates a production, which is immediately converted into cash at harvest time. But without maintenance, productivity decreases until disappearing.

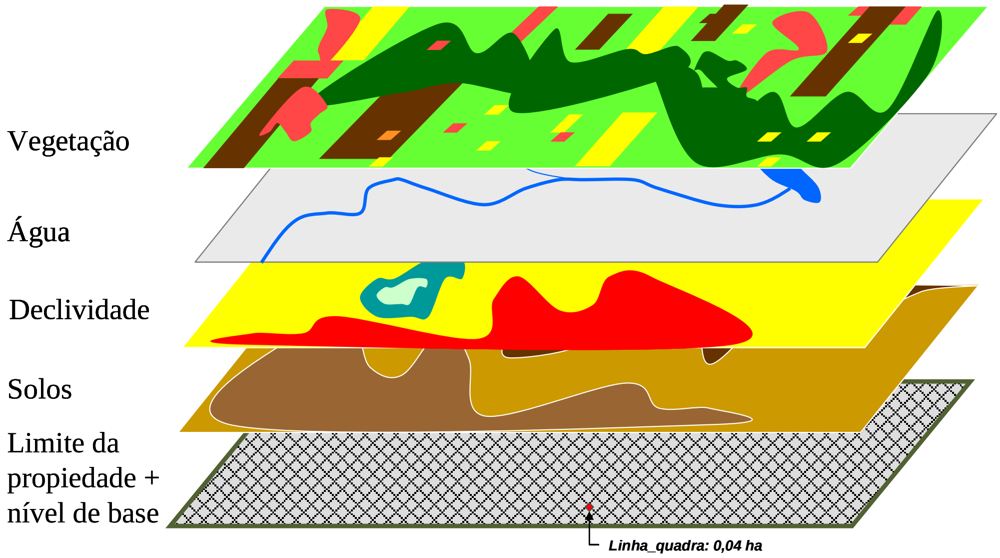

Figure 1: Spatial elements of a farm

This spatialized package calculates the whole production of the farm and makes the cover to evolve naturally: without a producer, a landscape of the farm evolves progressively toward forest.

Dynamics

The state-transition diagram (Figure 2) shows all the different covers available in the model and the different ways they evolve and change, through transitions. The green transitions correspond to natural evolution while the red ones are due to human activities (cutting, planting...).

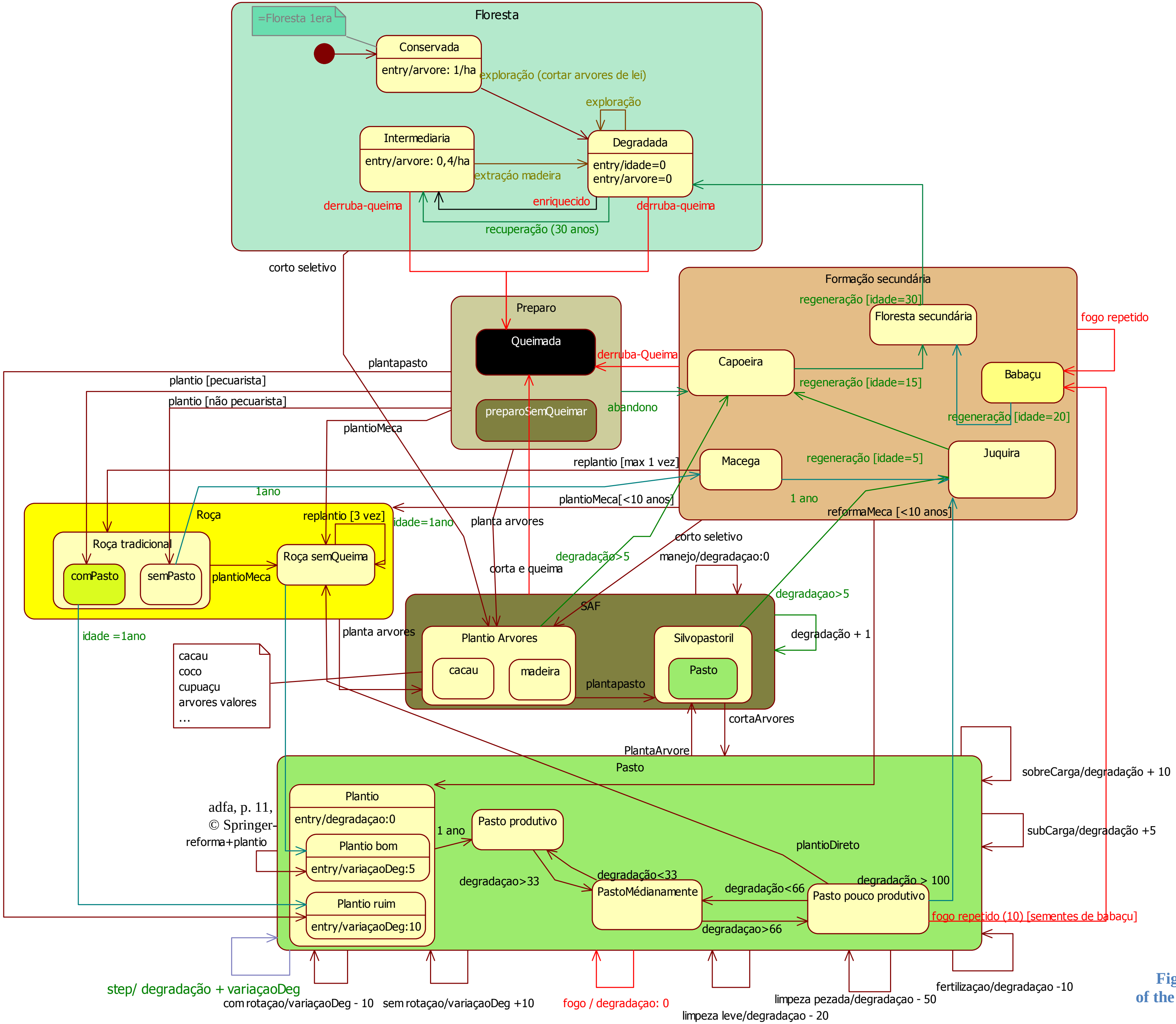

Figure 2: State Transition Diagram of the vegetal cover evolutions

The second package contains the family aspects. An agent (a family of *N* members) has two main features: his labor-force and his money. He uses his family labor to achieve the agriculture works on the farm or to sell it as external manpower. This labor-force corresponds to an amount of available working days that decreases with the performed tasks. This quantity is reset to its maximum at the beginning of the year (Figure 3). While he receives money at the harvest time, he spends a part of it for the family consumption and for all farming operating costs including the purchase of cows and the temporary labor employment.

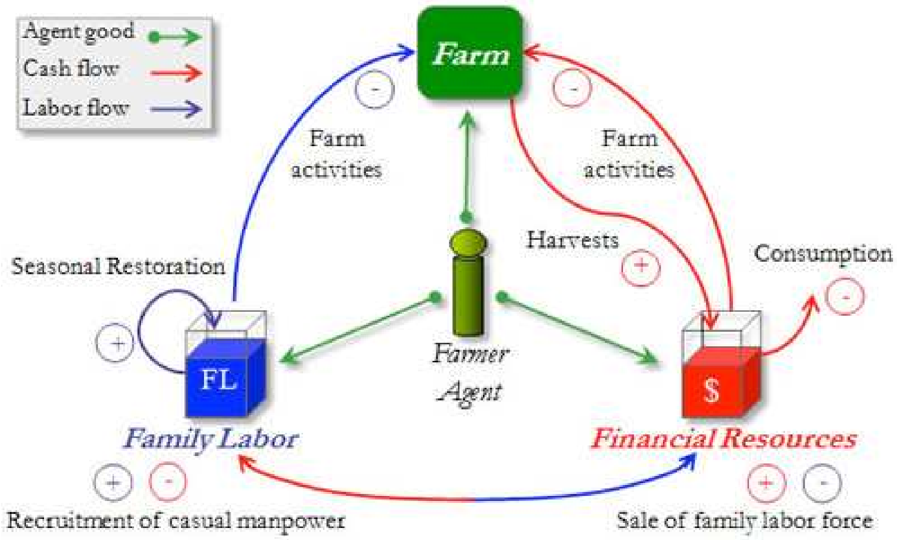

Figure 3: Systemic diagram of a farmer agent

A family is associated with a *Priority* (or strategy) that consists in performing farm activities oriented towards agricultural preferences. The priorities of the model are *Breeder, perennial Planter, Grower* and *Diversified.* For example, by choosing to be

Grower or Breeder, a family cultivates his land *favoring* his specialty. But this choice does not necessarily mean to neglect the other crops already present on the farm. Figure 4 shows the scenario 0 where, each year, the agent starts by performing its essential activities; afterward he does the activities related to its priority. Thus, even if his strategy is Planter, an agent begins cultivate a few parcels of annual crops for his food security and performs its basic rancher tasks (minimum management of the herd and the pastures). The rest of his labor force is then dedicated to his perennial crops.

In the current version of the model, an agent cannot change its priority. Thus a simulation of a scenario is run to its extreme consequences, even if the family situation is unsustainable.

As agents are limited in human and financial resources, their preferred activities will be applied after the essential activities that consist in insuring food for the family and maintain the herd and the crops already implanted.

From the scenario 0 main diagram (Figure 4), each sub-activity is described in detail by other activity diagrams. For example, the diagram of Figure 5 illustrates the "food security" sub-activity. It presents the activities of a producer (Rancher or other strategy), who dedicates a part of his workforce to ensure his food security. After having calculated the necessary area, he selects some plots, burns them, implants annual crops, maintains them, then harvest them. Several tests may constrain this process.

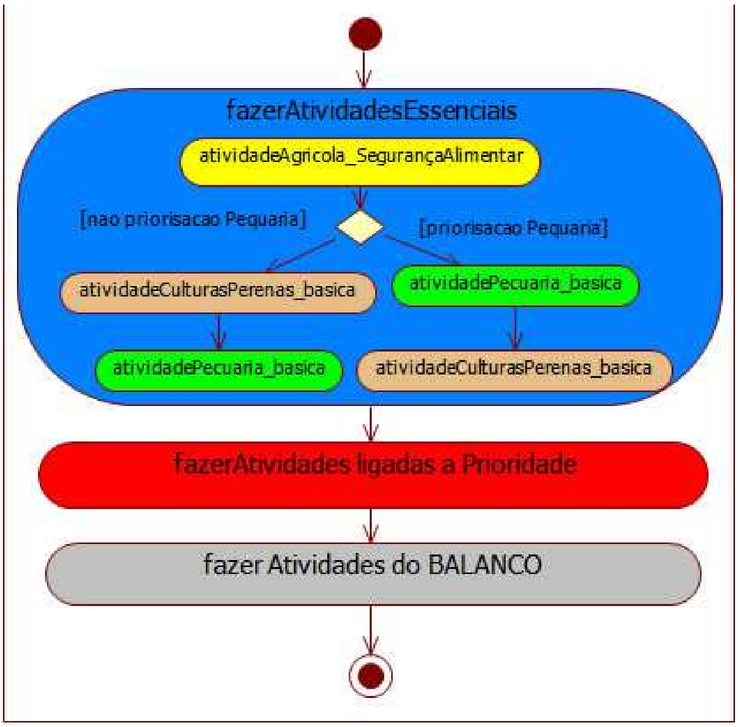

Figure 4: The activities of the scenario 0

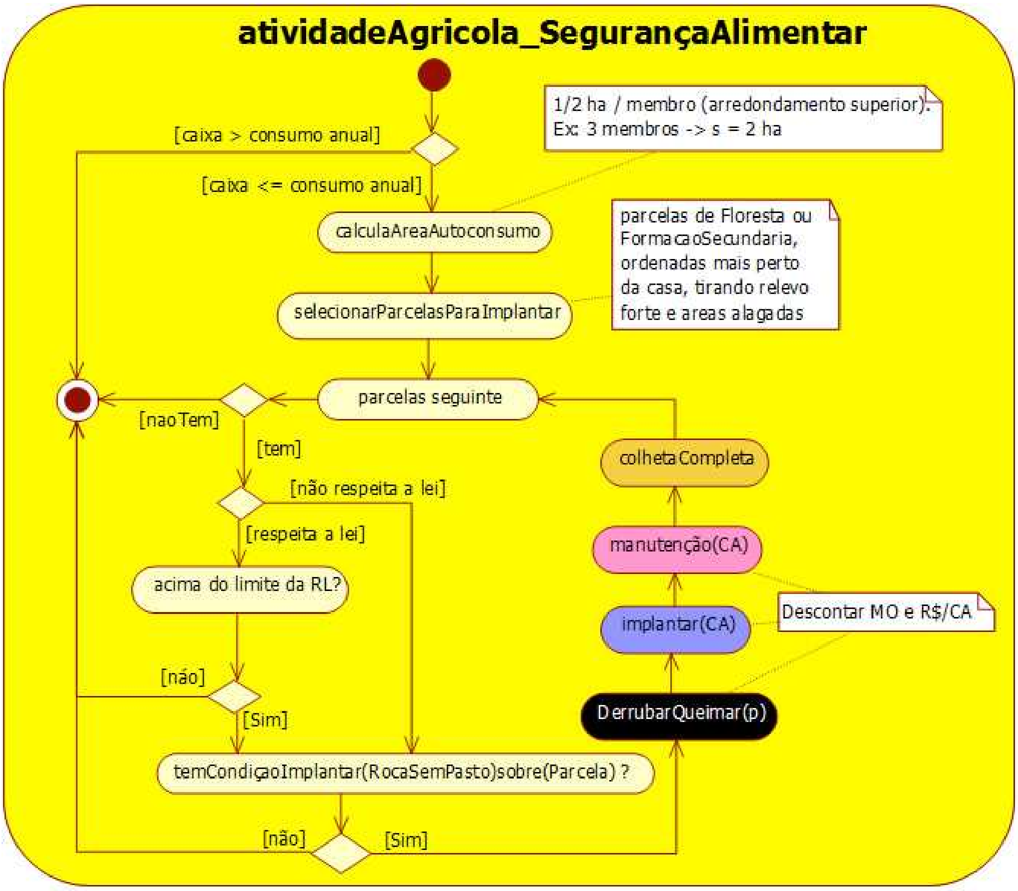

Figure 5: Activity diagram for "food security"

Obviously, for each priority, it is necessary to draw a specific diagram. For space reason, they are all presented on the (Amaz, 2012) web page.

First results

The model was implemented on the Cormas platform (http://cormas.cirad.fr), but all scenarios have not yet been finalized. Today the scenarios 0 and 1 are implemented.

The following results are obtained from simulations using a 100 ha property already partially cleared and with a family of 5 members including 3 workers. The initial cash is 1000 $ per person. A color code was attached to each type of cover. The following figure presents the initial state of the simulated farm.

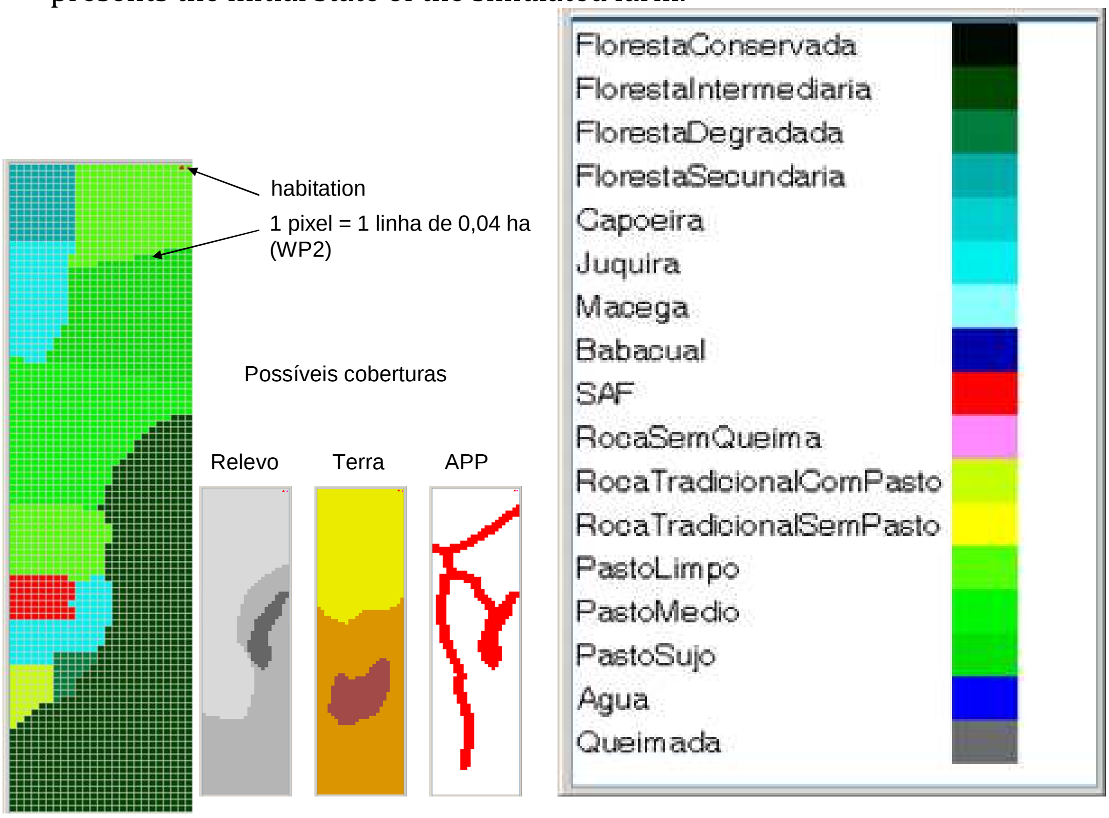

Figure 6: View of a farm and legend describing the color codes

The two graphs, below, present the family cash, according to scenario 0 and 1. For each graph, 4 curves represent the priorities.

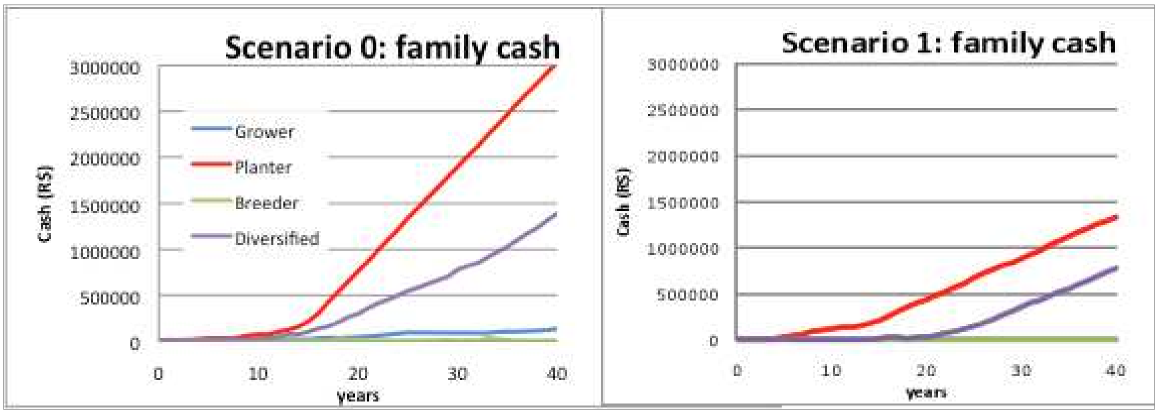

Figure 7: Comparison of family cash according to the 4 priorities and to the scenarios 0 and 1.

Due to the model simplifications, the output cash does not reflect any realistic variable: the family consumption remains unchanged regardless of the income. But we know that consumption generally increases with income (purchase of a vehicle, school, ...). So, the economic values obtained are too high. Here, the interest is to compare these probes for different strategies without paying attention to the magnitude.

Whatever the scenario, the Planter priority has better incomes than other strategies: despite the non-production period (3 years for the cocoa) and the high costs of maintenance, of inputs and of labor, the crop incomes compensate these charges. However, the price per kilo (4 R$/kg) is quite high in the model; in addition, it is fixed, which is seldom the case on the markets (especially for the cocoa prices). On the other hand, besides the fact that they are subject to market fluctuations, perennial crops do not offer flexibility: unlike a cattle for example, a family cannot sell early a part of his culture in case of urgent need (accident, disease...). Because the risky events do not occur in this model version, the incomes of the perennial crops are over estimated.

Compared to scenarios 0, the scenario 1 (compliance with the law) show in all cases an increase in forest areas and the recovery of environmental liabilities. But they also show that, whatever the strategy, the family incomes are significantly reduced, which suggests that these situations are not sustainable. So, a simple compliance with environmental law seems to be unreachable for the small-scale farmers in the Amazon. These legal constraints should be accompanied by agronomic assistance to find out new alternative practices to help the producers to respect the environmental law by improving their production capacities. To tackle this aspect, we will test the scenarios 2 and 3.

Discussion: loss of social characteristics to answer social demand

A history of model versions

The *Amaz* model is not yet finalized and a deep analysis of the simulations must be conduct to verify the model robustness (Grimm and Railsback, 2005). Nevertheless, *Amaz* inherits from a long history that started 8 years before with the *TransAmazon* model. This first ABM objective was to represent the advance of the pioneer fronts along the Transamazonian highway (Bommel et al., 2010). In that version, the settler agents have the possibility to buy or invade new land. Even if the attitude of the settlers is rather individualistic, the social dimension of the model was implemented through purchase relationships and observation of the neighbors to find the best land use strategy.

By seeking for alternative land uses in the Amazon, the Floagri project (funded by UE) has experimented several new land use practices on the field with small-scale farmers. Two experiments have been formalized into an ABM: the permanent field of annual crop (PFAC) and the forest management (FM) of the "legal reserve" (LR) of the farmer' property. Based on conservation tillage techniques, PFAC aims at recovering degraded pastures to avoid slash and burn practices, while FM consists in using the LR (80% of the farm area) without cutting the forest. By seeking to better assess the feasibility of these new activities, the social dimension of the *Floagri* model has been removed in order to be concentrated on the practices (Bommel et al., 2012).

In *Amaz*, the social aspect is still missing, except the politic side with environmental law. Nevertheless, the sociality is recovered through the use of the model. Indeed, by following the Companion Modeling approach (ComMod, 2003), the model is shared with the stakeholders and integrated into a process of monitoring and companioning of the rural dynamics. As ComMod is a way to build step-by-step exploratory models, people can be mobilized to participate into the modeling process. In a social phase, the model is assessed with the real farmers through participative simulations.

This involvement of the stakeholders allows revising the model and undertaking collective foresight investigations.

Futur use of the model

As it appears in a majority of modelling processes, the assessing phase requires feedback on model design. In order to make this assessment more lively and efficient, we have conceived a tool for drawing activity diagrams and executing them immediately. Thanks to this new opportunity, the actors can quickly understand how the model works and are able to criticize and modify it. This innovative executable UML editor enables the involvement of stakeholders in co-designing ABM for participatory foresight simulations. The editor has been experienced with Uruguayan breeders faced to climate change (Bommel et al., 2011).

Thanks to a joint use of *Amaz* and the UML editor, we want to address several challenged questions:

• For the settlers, what may be the viability of their farm over time?

• For technical and extension services: how to support the deployment a sustainable practices?

• For the policymakers what incentives can modify the current trajectories of land use?

By using the model with small-scale farmers of the Amazon region, we hope it will facilitate the emergence of new and more efficient practices for farm management.

Conclusion

The *Amaz* model aims at seeking for alternative land uses in the Amazon. In order to reach a more sustainable development, we analyze the benefits and the constraints of rural activities. The principle of this analysis is to compare various production practices starting from the same initial conditions, with agents adopting various strategies and a set of specific constraints.

Our first results conclude that a strict compliance with the law (do not deforest 80% of property) is ecologically better, but is not economically sustainable if the agents perform their standard land use activities.

By adding extra modules, an agent will have to comply with future strengthened legislation. Thus, the joint use of Amaz with an executable activity diagram editor will enable the collective design of new practices. So, we hope that this model could become a useful tool for the small farmers. By easily modifying the behavior of an agent, they could virtually assess the efficiency of new practices on their farm. We also hope that this tool could become a tool to facilitate the dialogue between different stakeholders in the Amazon.

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