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Benchmarking humanitarian support: Empirical agent-based modeling of development action types in Nigérien villages

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1 Abstract

The purpose of this article is to simulate and analyze the impacts of development interventions on the population of three different sites in Sahelian millet-cropping Niger (Sahelian Africa), taking account the differentiation of social and agro-ecological constraints on the different types of villagers. The work is based on a previous article (Saqalli, 2006), which has shown that using an individual Agent-based model (ABM) is a relevant approach to integrate agro-ecological, social and economic characteristics of a system and that family internal rules have strong impacts on village and environment evolutions. Two development project interventions are simulated in a context of no land scarcity: inorganic fertilizers availability for farmers and an inventory credit technique based on millet yields that some villagers may choose to use. Two rationalities are tested, one upon economic values and the second upon the intra-village "reputation" gains. Our results illustrate that a village cannot be considered as a whole and project operators must take in account the precise target population rather than all adult villagers. Project involvements concern only sites where savings for securization or intensification are possible: These proposals need actually some food security and investment capacities that are largely conditioned by family manpower and size. Inorganic fertilizers have little success without any intensification process in a context of good land availability. Inventory credit intervention engages a maximum of 25% of the population in the site with medium agro-ecological conditions. Reputation has little effect on the population behavior and should be considered more as a local wealth estimation factor between villagers. Therefore, one should consider these proposals as a potential support tool for a limited part of the population capable to go beyond the survival level, but not as a global poverty-alleviation panacea.

Key-words: farming systems, individual Agent-based model, Niger, development interventions

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1 Introduction

The low impact development operators have had on rural societies in Sahelian Africa for half a century has created a huge research debate within and between scientific disciplines, but also in the development arena (Hambally, 1999; Lavigne-Delville, 1999; Mortimore & Adams, 2001). The debate was widely open after the food crisis¹ Niger suffered in 2005 (Médecins Sans Frontières, 2005; Harragin, 2006). In front of this recurrent and desperate failure, the issue is to improve the relevance and the efficiency of development projects (Decoudras, 1990; Watkins & von Braun, 2004; Dollar & Levin, 2006).

A proper understanding of the Sahelian village production system is a prerequisite for successful development actions and requires prior recognition of the inherent complexity of this system. Land tenures are various and complex (Le Bris *et al.*, 1991; Lavigne-Delville, 1998; McCarthy *et al.*, 2000). Non-separable interactions between the on-farm and off-farm production activities and consumption decisions (de Janvry & Sadoulet, 2003), the repartition of the assets between villagers within the village and the family and the multiple purposes of the strategies are some of the socio-economic factors with a direct effect on the success of production-supporting actions. Actually, many factors may modify the way a development proposal is considered by a village population. Beyond the informal but recurrent local reinterpretation of the rules of the development project itself (Laurent *et al.*, 1994; Biershenk *et al.*, 2000; Laurent, 2000), the benefit of a development intervention varies with the type of concerned villagers (Lavigne-Delville, 1999; Marou, 2005). As any proposal, a development action should thereby also integrate a "marketing" approach: who are the real focused populations of a development action in a Sahelian village and what factors condition the adoption of a proposal within a population? Because of the size and the type of this actual focused population, what is the extent of the adoption and the real impacts on environment and society of such proposals? Are ABM tools efficient enough for the analysis of such a complexity and what sort of information do they provide that other model types do not? These are the questions that the article considers and analyses. For that purpose, we selected two actions that are emblematic of development strategies in the country:

- Niger having one of the lowest inorganic fertilizer use rates (0.27 kg/ha) (World Bank, 1997), inorganic fertilizers are considered by many development operators as the bottleneck for farming system intensification and income increase in Niger (de Rouw & Rajot, 2004; Ouédraogo, 2005). The purpose of these operators is to support farmers to use inorganic fertilizers in food crop fields and vegetable gardens through farmers' organizations, by increasing the availability of inorganic fertilizers at the village-level and the knowledge on their use, with an emphasis on the microdose technology (Tahirou & Sanders, 2005; Gérard *et al.*, 2007), thereby reducing inorganic fertilizers waste and the weed impact (Muehlig-Versen *et al.*, 2003). The promoted inorganic fertilizer is Diammonium Phosphate (DAP). Group members can buy inorganic fertilizers at market price. Groups almost entirely consist of either women or men, using inorganic fertilizers for gardens, cash crops or cereal fields.
- The second proposal is the warrantage, also named inventory credit. It is a credit technique based on the use of farmers goods set down as a guarantee in a warehouse. This technique is actually applied in Niger under various modalities, depending on the site, the Microfinance Institution (MFI) and the Farmers Association (FA) involved. Usually after harvest, farmers stock a part of the yield in a reliable warehouse as a guarantee for the credit operator. In exchange, this last provides a credit equivalent to 100% of the value of the stock at the time of the deal², with 10% of the initial stock value for the FA as storage and fee costs. The farmer reimburses the credit by buying back the stored millet and sells it on the market at high prices (usually during "soudure" times). The benefit due to price increase during the storage period belongs to the farmer. The objective is to provide better access to financial resources (Badamassi, 2006) and for income securization, by compensating millet price fluctuations (Pender *et al.*, 2006).

¹ Choosing between "famine" and "food shortage crisis" to describe what actually happened in 2005 reflects the political position in the development arena

² It means that the credit value is the yield portion the farmer let in the warehouse, upon the price at the harvest, usually around 0.15 €/ kg.

All the elements of the system to include in the evaluation of this relationship cannot be analyzed in a systematic and/or an experimental manner (Ahrweiler & Gilbert, 2005), which implies to model the system. As reviewed by Lambin *et al.* (2000) and Bousquet & Le Page (2004), Agent Based Models (ABMs) have been found particularly useful for simulating the multi-disciplinary and multipurpose reality of the rural world. In the present study, the focus is on the project intervention and the population, the target area being south-western Sahelian Niger.

2 Description of the study sites

The program which supported our research was hosted and managed by a consortium of development and research operators working in Niger and farmers' associations. The institutional position given by our own involvement into a development project helped us to get access to the network of experts in Niger. The operators of the consortium had completed extensive literature and data sets resulting from 20 years of agricultural research and are implementing the two selected development proposals in several sites of the rainfed part of Niger. The three sites represent 3 contrasted situations of the rainfed agro pastoral zone of Niger (Figure 1), namely Zermou in the region of Zinder, Gabi in the region of Maradi and Fakara in the region of Tillabery. The latter was the main location where we elaborated our social hypotheses, which were then extended to the two other sites with the support of the available literature (Luxereau & Roussel, 1997; Waziri Mato, 2000; Mortimore *et al.*, 2001; Jouve, 2003; Yamba, 2005).

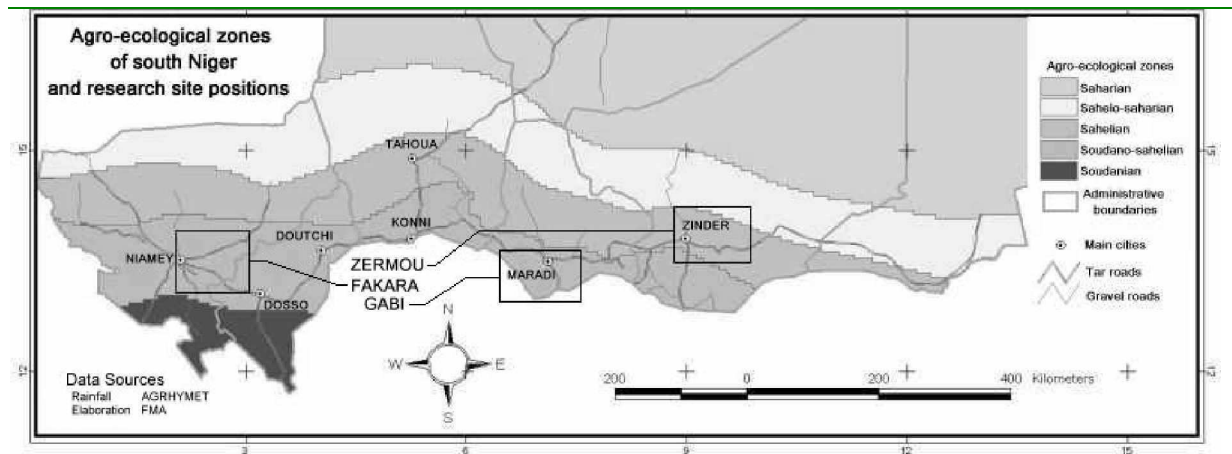


Figure 1. Rainfed Niger and locations of the three study sites

These regions are: (i) situated in areas with rainfed agriculture (10% of the territory), (ii) close to a regional urban pole, and (iii) linked to the main farming ethnic groups of the country (Zarma around Niamey, Hausa in Maradi, and Hausa / Hausa-speaking Kanuri in the region of Zinder). The sites we chose in these three regions: (iv) are considered as poorly resources-endowed and (v) are sites of both active scientific research and development support from operators (Gérard, 2002) working for more than ten years in Niger. Each site covers 45 km per site, an area of about 2000 km². The differences between the sites are summarized in Table 1.

Rainfed millet and sorghum-based agriculture is the main activity in terms of land occupation and manpower requirements in the 15% of the territory where it can be practiced. It is managed in an extensive and anti-risk approach: the rainfed part of the country experiences a low to moderate rainfall between 200 and 800 mm, distributed in one rainy season from June to October, but its main characteristic is its high spatial and temporal intra-annual and inter-annual variability. Soils have a very low fertility as well as a poor water and cation retention capacity (Graef and Haigis, 2001). Manure is the main local fertilizing method, but is not available in quantities large enough to meet demand (La Rovere, 2001) while at the same time inorganic fertilizers are still expensive. The population has conquered its own national rural “frontier” in rainfed areas by extending crops and settling new villages (Guenguant *et al.*, 2002). This settlement movement is fully complete in the central southwestern part of rainfed Niger (Region of Maradi), as described by Mortimore *et al.* (2001). It fully continues in the region of Zinder, central southeastern Niger, but seems to slow down in the region of Niamey, western Niger (Saqalli *et al.*, 2007).

Male farmers are seasonal migrants during the dry season, from October to May, to work usually as small traders (Timera, 2001; Rain, 1999). The money they brought back home is an important source of income for the remaining family members, around 290 € per family per year (Reardon, 1994; Mounkaïla, 2003; Saqalli, 2006). These funds are mainly used to fulfill food requirements that agriculture doesn't cover any more, for male

ostentation purposes such as cigarettes or sunglasses and to cover expenses for social and religious ceremonies³. Migrants buy small ruminants coming back from migration, thereby saving some money from the requests of the enlarged family, and allowing them to pay the next migration travel expenses, usually just after crop harvest (Saqalli, 2006).

Dry season vegetable gardening can be practiced only in some villages where wells give access to shallow groundwater in talweg fields. Social access to gardening varies according to the site: it is actually restricted at the Fakara site to married and respectable women with family manpower, by borrowing fields after the millet harvest. This activity provides on average 52,50 € per gardener cultivating per year (Saqalli, 2006). Because of better access to markets, larger acreage suitable for irrigation and therefore a better profitability but also a social evolution pushing away women from fields, Gabi has seen a shift in the gardening activity from a female driven traditional mode to a pure male activity. The site of Zermou has seen the same social shift but has access to a very small suitable acreage.

Table 1. Factors of differentiation between the three sites

| | Zermou | | | Fakara | | | Gabi | | |
|--|---------------------------------------|-------|-------------|--|-------|----------|-------------------------------------|-------|-------|
| Location | Zinder Region, Eastern Niger | | | Tillabery Region, Western Niger | | | Maradi Region, Central Niger | | |
| Annual rainfall | Mean: 350 mm | | | Mean: 450 mm | | | Mean: 550 mm | | |
| Average soil fertility | Variability: [70-525 mm] | | | Variability: [180-675 mm] | | | Variability: [275-775 mm] | | |
| Soil arability proportion (%) | Poor | | | Average | | | Good | | |
| Initial Agronomic potential * | Valley | Plain | Stony hills | Valley | Plain | Plateaus | Valley | Plain | Hills |
| Access to shallow water | 0.1 | 69.9 | 30.0 | 3.9 | 79.6 | 16.5 | 18.1 | 60.0 | 21.9 |
| Migration destination & impact on other activities | 2 | 1 | 0 | 2 | 1 | 0 | 2 | 1 | 0,5 |
| Migration constraints | Yes | No | No | Yes | No | No | Yes | No | No |
| Migration constraints | Gardening incompatible with migration | | | No competition between gardening & migration because of the gender differentiation | | | Gardening compatible with migration | | |
| Migration constraints | Transport costs: 45 kFCFA | | | Transport costs: 30 kFCFA | | | Transport costs: 5 kFCFA | | |
| Migration constraints | Racket risks: 2% | | | Racket risks: 1% | | | Racket risks: 0,5% | | |
| Women activity | Sheep raising | | | Sheep raising & gardening | | | Sheep raising | | |
| Men activity | Farming, migration & gardening | | | Farming & migration | | | Farming, migration & gardening | | |
| Present time inheritance system ⁴ | Local traditional | | | Local traditional | | | Local Muslim | | |

3 Methodology

3.1 The overall approach and assumptions

The overall research methodology followed an iterative process between field investigations, discussions with local experts and modeling. The modeling approach was supported by a two-year field investigation and participatory observation period similar to that described by Bogdan & Taylor (1975). This observation period concerned a group of villages and local organizations. Repetitions along interviews and cross-checking between sources were the criteria of validation of these rules. They are then compared to behavior descriptions and rules in the available literature. As for the model rules, the different scenarios were also defined on the basis of field observations, discussions with experts and a literature review.

Our strategy is to compare both interventions in terms of impact on the population and under different local environments, based on our hypotheses regarding local villager logics and behavior. As a method combining rather than juxtaposing different disciplines, we do have to formulate numerous hypotheses:

1. The success of a development action is not defined by its very characteristics but results from the villagers perception of this action, whatever its intrinsic quality. The factors and constraints selected for implementation in the model are thus defined on the basis of the villagers perception as the ones which determine the interest in the development actions. This model is therefore individual-based: each villager Agent has its own behavior, depending on its social characteristics and constraints, in order to combine at this very level all the complexity and the specificity of each individual in a village (Deffuant *et al.*, 2002), but also to avoid the so-often assumed but rarely clearly defined “household” unit, which is not relevant for sahelian rural situations (Gastellu, 2006; Saqalli, 2006).

³ Based on our interviews, each marriage can cost 1 150 €, shared within the community. In addition, the dowry should be given to the bride’s family (a sum equivalent to two bulls, i.e. almost 300 €). Tabaski, the main Muslim feast, where a sheep should be sacrificed, is a time when sheep prices reach 5 to 6 times the usual price (from around 15 kFCFA ~ 22.5 € up to 90 kFCFA ~ 135 €).

⁴ The customary so-called traditional mode is considered as favoring one of the male descendants, usually the elder, by giving him almost all the concerned assets, leaving symbolic elements and some small livestock to the others. The local adaptation of the Muslim inheritance system shares the assets between all the male heirs, splitting half of the leg to the brothers of the dead and half to his sons.

2. The model is empirical and agent-reactive: villager behaviors and processes are not cognitive and the different small steps of the various activities are implemented as simple as possible to maintain the global consistency of the system. Villagers simply do what they have to do and react over time and as a function of the events without cognitive functions that would require absolute rather than relative parametering of values on social issues. The only cognitive function of villagers concerns our main target: the villager involvement in a development intervention.

3. Considering all the components of a system and simplifying them is more relevant than neglecting some activities by focusing on the one which seems to be the most important (Alacs, 2004; Amblard & Phan, 2006). This model is therefore not based on the binary relationship between a villager and the project but includes the project actions as a component of the pattern of activities of a villager Agent.

3.2 Investigation methodology

3.2.1 Assessing the individual-based but family-related organization of a rural village

The agro-ecological part of the model was defined through available literature data (Gérard *et al.*, 2001; Turner and Williams, 2002; La Rovere and Hiernaux, 2005). Millet price and rainfall data as well as the functions relating millet growth to fertility and rainfall came from ICRISAT and ILRI databases.

The social family part of the model was developed through a literature review, transects, interviews and local perception-based regional maps (ZADA) (Bonin *et al.*, 2001; Caron, 2001) described in detail for the Fakara and Zermou by Saqalli *et al.* (2007). The semi-direct interviews of 126 persons from 4 selected villages focused on the main activity carried out by the interviewed person at the time of the interview. The model was then extended to the two other sites with the support of a ZADA in the site of Zermou, four village Participatory Research Assessments (PRAs) using the methodology and principles of Chambers (1994) and twenty individual interviews for the Gabi and Zermou sites, as well as a review of the available literature.

3.2.2 Assessing the practical mode of implementation of development actions.

Our long-term field investigation also allows investigating the complex relationship between project and villages and assessing the practical implementation of development actions. We tried to analyse these actions from the operators point of view and the villagers' one, using a participatory observation approach⁵. We first used the operators' official documents or documents coming from other operators as a mainframe to confront unofficial expert communications and local situations.

The analysis of the development operators practices was done through different cross-checkable methods: (i) 4 to 12 villagers for each study site were re-interviewed on their personal relations with development projects. These persons were selected because of gender and level of responsibility and their will to interact⁶. In the same way, nine elders were interviewed on their perceptions of the history of local development actions; (ii) development actions results are recorded in village-based registers that we collected and compared with head office' records but also with our own village semi-direct interview data; (iii) By staying in villages and remaining as unobtrusive as possible, our everyday presence allowed observing transactions and comments between villagers and development stakeholders with a low level of perturbation and so, to have access to the interface between the project corpus and the village one.

3.3 Agent based modeling

The selected ABM platform is CORMAS (Common Resources Management Agent-based System) developed by CIRAD (Bousquet *et al.*, 2001). The model was split into an agro-ecological part and a socio-economic part (Figure 2). The modeling methodology, including the parametering functions and related sources for the agro-ecological and village socio-economic modules is fully described in Saqalli (2006).

⁵ The best moment for observation was the time when both social groups were encountering, during meetings, visits and interview times.

⁶ It often happens that this depends on their own frustrations, which means that we had to integrate their testimonies in their own political and social context.

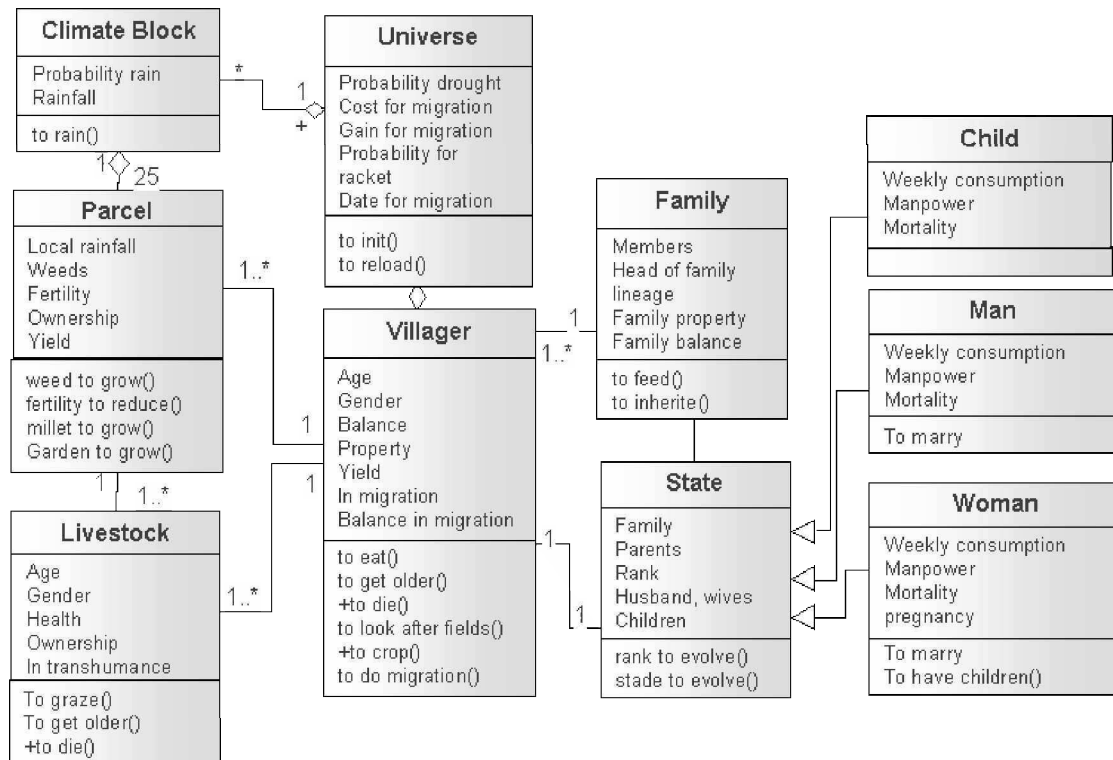


Figure 2. Unified Modeling Language architecture of the SimSahel model

3.3.1 Building the village module

Individual agents are defined as equivalent, which means that they have the same attributes: only the values of these attributes vary, defining each agent and its characteristics (Verhagen & Smit, 2003).

At the model initialization, fifty villager agents are created in the virtual environment. Initial villager agents are from various ages (from 1 to 55 years old), gender, lineages (with a hierarchy from 1 to 4, as a measure of the power of each big kinship group in the village) and land property (between 3 to 5 map cells). After the initialization step, gender and family rank for a villager agent are the most important factors within the village context. They determine the access to all the social and/or economic activities, i.e. marriage, property, food and money redistribution, millet farming and migration for men, gardening for women. Ranks are defined for all child agents but evolve for all adult agents in each family. They are updated at the beginning of each time step, according to newborns, new marriages, reaching adulthood and deaths. The first rank in a family defines the head of the household. However, the family's head does not manage all the multi activity system of the family but only millet farming activities. Other activities (livestock-keeping, migration, gardening, food redistribution) are under the sole responsibility of the worker: each villager agent should sustain itself but also its dependents, i.e. all people in the family with a lower rank and directly related to it⁷.

Families can expand their land properties only if the family annual consumption is higher than the last yield⁸. The extension capacity depends on their lineage values, their ratios between the available family manpower⁹ and the family size (Gavian & Fafchamps, 1996), and a distance-to-village opportunity cost factor (Loireau-Delabre, 1998). Only married adult males can have access to land ownership. As a strict condition to become by this way a village "citizen", each male adult agent has to marry at least once and up to four times. Earning enough money to afford the dowry is therefore vital for each bachelor.

The model has a weekly time step and it is spatialized through a dynamic cellular automata matrix of the model, where each pixel is a parcel of the village territory, introducing the data-derived spatial distribution of soils characteristics (fertility, access to shallow water) of the village territory, the simulated land tenure distribution but also the rainfall spatial variability as observed from the local ICRISAT raingauge network (Gérard, 2005). Biophysical and farming processes are defined for each pixel as identified by the villagers and from literature data.

⁷ It groups all the children but also younger brothers and sisters, and wives for the husbands.

⁸ It happens quite often, particularly in the case of Zermou (AQUADEV, 2006).

⁹ The manpower unit is defined as the Farming Labor Unit (F.L.U.) For our case and based on our observations, female and male adult manpowers are equivalent (one can even consider that the female manpower is more important locally) and equal to 1. We condition the child manpower capacity on age, i.e. for a child i in the village: $\text{Manpower}(i) = \text{Age}(i) / 20$.

3.3.2 Simulating villagers' production activities

Agriculture. Only male adult agents can crop millet fields during rainy seasons in all the three sites and can garden on borrowed fields during dry seasons for Maradi and Zermou sites. For the Fakara site, the latter activity is restricted to female adult agents. The sequence of cropping actions a male adult agent should follow, i.e. sowing, weeding once or twice and harvesting, is conditioned by the diagnosis of available manpower and minimization of expected production losses. Crop growth is governed by the available manpower a villager agent can mobilize to carry out the right cropping action at the right time, defined by rainfall distribution and by the fertility rate at each time step. A parcel's fertility evolves as a function of crop growth, a weeds impact factor and animals manure during dry seasons. Crop yields result from a combination of the crop growth, weeds, fertility and management.

Gardening. For their dry season vegetable gardens, female adult agents follow an equivalent sequence of actions. Only female adult agents with stepdaughters or with unmarried daughters at least 12 years old can have access to gardening. These can mobilize the available female manpower from then on in a similar fashion than the head of the family for millet farming.

Migration. Only male adult agents more than 16 years old have access to the migration activity. The price for the roundtrip travel is the major constraint for leaving. The date of departure depends on the family rank, i.e. the number of dependent relatives. The weekly gain is a function of the site, season, and number of years of experience. To return home, the migrant should overcome two constraints: (i) for prestige reasons, a male adult agent cannot return to his village without a minimum amount of money, at least the roundtrip ticket for the next migration, i.e. $2 * 45.75 \text{ €}$. (ii) Each migrant agent has a certain probability to be racketed by the customs services he meets (Table 1).

Livestock keeping. It is here limited to a saving scheme. Each year, individual gains (crop yields, migration, gardening) can be transformed into livestock, with a depreciation factor. If family yields are good enough, villager agents buy animals after crop harvest, when they have grain to sell; however, it is the time when millet price is the lowest (around 13,75 € per 100 kg bag). When the granary is quite empty, they sell animals to buy millet, but at that period, millet price is high (27,50 € per bag on average). This 50% loss can be considered as a livestock keeping cost. Coming back from migration, the migrants buy small ruminants they feed during the rainy season. At harvest or sometimes before, they are sold to pay the ticket for the next migration. Animal fattening is in this case considered as compensating the 50% loss.

Fertility management and manure: Three fertility restauration processes are considered: The natural regeneration by shrub and weed growth is simulated through a serie of functions of fertility originated from simplification factors issued from d'Herbès *et al.* (1997) and Wesel *et al.* (2000). The impact of animal manure varies: animals graze at day time their allowed territory (table 2) with no human management. Half of the animal manure is by then spread in grazed areas and the other half in corrals at night (Ayantunde *et al.*, 2000; Ayantunde *et al.*, 2002), which allow villagers to spread manure on chosen fields (distance to village, fertility).

3.3.3 Assessing development action types

Action types are gender-specific. Warrantage and fertilizers are proposed to villagers at $t=0$. For each adult and married villager, choosing to be involved in one of the actions is the only cognitive function: it is based on a gain comparison between the personal experience on annual income with or without using the action type. The gain is based on food and income stock. In case of no experience, all adult villager Agents who manage millet fields or gardens tries the action type for the coming year.

Warrantage.

Inventory credit choices are made after harvest. As a saving choice, the first step is to determine if the agent (i.e. the head of the family or, if absent, the highest ranked adult) has the capacity for saving. It means that we consider that every villager relies on the necessity to keep at least enough millet for half a year for all the family members who rely on him/her: $SM_{fi}(t) > CA_{di}(t) / 2$ (1)

With: d_i : the number of family members of i relying on i at t ; $SM_{fi}(t)$: i family millet stock at t ; $CA_{di}(t)$: annual food consumption of the dependents d_i ;

The second step is then a cognitive decision based on personal experience, through a comparison of the mean gain during past years with saving through warrantage and past years with no savings or with saving through livestock: $W_i(t-1) + X_{fi}(t) > NW_i(t-1) + Y_{fi}(t)$ (2)

With: $W_i(t-1)$: the total value of the previous years with warrantage; $NW_i(t-1)$: the total value of the previous years without warrantage;

If warrantage was used the last year [$t-52$; t]: $X_{fi}(t)$: the total "gain" of the family of the last year [$t-52$; t], including the difference in cash of the value of the livestock between $t-52$ and t . The "gain" is either "reputation" in the reputation scenario or "income" in the economy scenario; $Y_{fi}(t) = 0$.

If warrantage was not used the last year [$t-52$; t]: $X_{fi}(t) = 0$; $Y_{fi}(t)$: the total "gain" of the family of the last year [$t-52$; t], including the difference in cash of the value of the livestock between $t-52$ and t .

Warrantage is in our case a financial transaction: selling millet through this action type allows buying its own inorganic fertilizers at the same price (majoring a 0.15 € per bag for shelf stocking) than it was sold.

Fertilizers.

Inorganic fertilizer applications is possible throughout the millet cropping season. Only millet field or garden managers can buy fertilizers. The price of the bag of inorganic fertilizers is 50 kFCFA, i.e. 75 €. According to the microdose recommendations (Tahirou & Sanders, 2005), 0.2 bags of inorganic fertilizer are poured on one parcel of 1 ha, meaning that fertilizing one cell in the model cost 10 kFCFA, i.e. 15 €. Gardens need 10 times this value, meaning that, because we consider that one garden is one tenth of a cell, fertilizing a garden also cost 15 €. As a production choice, the first step is to determine if the agent has the financial ability to afford some fertilizers. Setting aside at least enough millet and/or cash for half a year requirements for him/herself and its dependants, the ability depends on whether or not the value of the family's millet and cash stock exceeds the fertilizers needs¹⁰. The capacity is defined as follows: $SM_{fi}(t) + SC_{fi}(t) > NF_i(t)$ (3)

With: $SM_{fi}(t)$: millet stock of the family i ; $SC_{fi}(t)$: cash stock of the family i ; $NF_i(t)$: inorganic fertilizers needs based on the property which had a better mean production with inorganic fertilizers than without.

The second step is also a cognitive decision based on personal experience, through a comparison of the mean gain from past years with and without fertilizers, similar to that used for warrantage.

Inorganic fertilizers impact start from their application. They have several effects on millet depending on the crop development (seedling, sowing, maturation and harvest stages). During the maturation stage, there is a risk of 1% per week to lose the harvest in fertilized fields because of the chemical burnt it can occurs (de Rouw, 2004; Koning & Smaling, 2005).

For each site, thirty simulations were run for a period of sixty years (i.e. two generations) corresponding to 3120 weekly time steps. Simulation outputs were obtained for the entire village, at family level and at gender and age group levels. Village level simulation results are compared to available data, i.e. our macro level field investigation results, literature review and the Niger national census, in order to access the consistency of the model. The two development actions are then compared individually or in combination. Table 2 shows the combination of scenarios and their abbreviations. As the village is founded at $t=0$, the first 5 years should not be considered as part of the simulation results as they are strongly affected by the initialization process.

| Sites | Control | Fertilizers | Warrantage | Warrantage + Fertilizers |
|--------|---------|-------------|------------|--------------------------|
| Zermou | ZEC | ZEF | ZEW | ZEFW |
| Gabi | GEC | GEF | GEW | GEFW |
| Fakara | FEC | FEF | FEW | FEFW |

4 Simulation results

4.1 Confidence building

To build some confidence in the model, we compared the simulated production assets from four scenarios with available information for the Fakara site (Table 3).

| FAKARA without projects | Family size | Family manpower (in FLU) | Livestock owned per family | | | % Area corralled with livestock | Household Sample size |
|---------------------------|-------------|--------------------------|----------------------------|-------|-------|---------------------------------|-----------------------|
| | | | Cattle | Goats | Sheep | | |
| Loireau-Delabre (1998) | 9,1 | 6,8 | 1,3 | 2,1 | | 36,9 | 221 |
| La Rovere (2001) | 8,6 | 4,8 | 0,7 | 0,1 | 0,1 | 10,2 | 366 |
| Tahirou (2002) | NA | 7 | 3 | 4 | | NA | 100 |
| Field observation results | 8,2 | 5,2 | 2,0 | 1,41 | 0,2 | NA | 67 |
| FRC (simulated) | 7,2 ± 0,2 | 5,7 ± 0,5 | 3,4 | 1,17 | 0,2 | 8,9 | NR |
| FEC (simulated) | 7,1 ± 0,2 | 5,4 ± 0,5 | 3,2 | 0,93 | 0,3 | 15,4 | NR |
| FRFW (simulated) | 6,9 ± 0,2 | 5,6 ± 0,5 | 2,8 | 1,37 | 0,5 | 10,4 | NR |
| FEFW (simulated) | 7,0 ± 0,2 | 5,6 ± 0,4 | 2,4 | 0,80 | 0,5 | 8,1 | NR |

FLU: Farming Labor Unit; NA: no data available. NR: not relevant

Data reported by different authors are actually highly variable among each other, particularly regarding herds: livestock ownership simulation outputs fit better with observations of Loireau-Delabre (1998) and Tahirou

¹⁰ We have eliminated the use of livestock as a potential cash source to buy fertilizers, as we never observed anybody selling animals to buy fertilizers in any case. This is consistent with the general assumption that animals should be considered as savings or speculation products by themselves but not as a source for productivity increase investment

(2002) than La Rovere (2001). As interview results are inherently highly dependent on the interview processes and the questioned issues, the fact that the latter author has mainly focused on livestock management in his work while the two former scholars have worked on villagers assets give us more confidence in the observation of Loireau-Delabre (1998) and Tahirou (2002).

4.2 Comparing sites with no development action implementation

4.2.1 Production assets: a structural geographic advantage

Average income evolves at first in a convex curve because of the generation effect: a very high adult per capita ratio during the first 5 to 10 years has positive effects on income (Figure not shown). But the children explosion during the 15 to 30 years period (Figure not shown) force the slope of the income curves of the three sites to become negative. However, the curve amplitude varies depending on the simulated site: Fakara and Gabi show equivalent declining curves, while income at Zermou is continuously significantly lower. Better conditions, both biophysical (rainfall and soil fertility) and economic factors (migration costs) as they are implemented at the Fakara and Gabi allow higher individual incomes, which facilitates the access to marriage for men, reducing therefore the delay for getting children.

As the decision to expand fields is conditioned by the food production level and yields are very low at this site, land occupation increases faster at Zermou than at the two other sites. Therefore, the land per capita ratio is higher in this site than the two other sites during the first half of the simulation period. But, as the manpower ratio of Zermou remains quite equivalent to the two other sites, villagers do not benefit from this rapid field expansion as they cannot crop all of it properly.

As a consequence, village population growth is equivalent for the Fakara site (585 inhabitants \pm 141 inhabitants at the end of the simulation) and Gabi (505 inhabitants \pm 131) but is significantly lower for Zermou (321 inhabitants \pm 97). The substantial differences between Zermou and the two other sites suggest that the Zermou site has exceeded a threshold resulting from the accumulation of higher constraints.

4.2.2 Activities distribution: site specific specialization

All three activities (agriculture, migration and gardening) grow in volume along the 60 years because of the demographic growth.

Income from millet agriculture per villager varies according to the site: Zermou shows a constant decline in the farming income and even a shift in the allocated labor for farming between the 15th and the 25th year (i.e. after the very rapid period of field extension in Zermou). The two other sites have similar trends, both strongly affected by a generation effect due to the progressive appropriation of new lands during this period, which does not occurs in Zermou. During at least the first half of the simulation, it seems that the Fakara population is more involved in farming and has higher farming gains than in Gabi. However, this last site is the only one to maintain its farming gains per capita and sees even an increase in the farming labor until it exceeds the Fakara figures between the 35th and the 45th year.

For the gardening activity, local social and economic rules dramatically change the situation: both hausa-populated sites of Zermou and Gabi restrict gardening to men. However, the Gabi site makes it possible to practice migration and gardening by the same villager at the same time, thanks to the immediate proximity of Nigeria, while this combination is not possible at Zermou. Consequently, the use of the very few gardening places of the site stops quasi totally¹¹. More land suitable for gardening (Table 1) and access to male manpower in Gabi allow a progressive increase in the gardening gain per villager. But this expansion is lower than in the Fakara, which may have benefited from the gender discrimination between gardening and migration (Table 1). Manpower involvement ratios for the zarma-populated Fakara and in Gabi do therefore concern different populations.

For the migration activity, while the three sites show no significant differences in the manpower allocation before the generation peak (year 10 to 20¹²), migration seems to be strongly affected by the access constraints (Table 1): While the lower cost for departure for Gabi allows progressively more people to leave and to bring back home more money than in the Fakara, it seems that the accumulation of disadvantages for the Zermou site (higher departure costs, more risks, poor agriculture gains) limits the extension of this activity at the beginning but the very low gain of agriculture and the impossibility to garden progressively forces people to reallocate their manpower on the sole available activity, i.e. migration.

¹¹ The potential acreage for gardening in Zermou is very low compared to the other sites: 0.52% (see Table 2)

¹² The generation peak affects migration before farming: migration is allowed for men after 16, even if they are not married, whereas marriage is a prerequisite to become farmers and land "owners". Getting married on the other hand stop the support from their parents for migration, which lower their financial ability to leave.

4.2.3 Inequality and sustainability: producing more for how long and for whom?

One should also analyze the sustainability of the considered systems as some sites show declining figures for production efficiency or land occupation ratios.

As defined by the model rules, Fakara and Gabi site population extends their cropped land taking account their manpower/population ratios. Land occupancy grows in Gabi by a temporally stable rate of 4,6% per year (Fakara, 2,4% and declining over time). Zermou villagers rapidly conquer their territory although they do not so much involve themselves in farming, because of the far more rapid decline of the fertility of the cropped land. This assertion is compatible with the literature for various zones in Niger, including the Damagaram where Zermou is located, but also other arable places in Niger for the end of the first half and the beginning of the second half of the 20th century. This conquering behaviour is usually described as a response to manpower scarcity but also as an “investment for the future” at family and village levels (Demont *et al.*, 2006; Bah *et al.*, 2006). Even with lower land occupation growths in the Gabi and Fakara sites, 60 years of continuous growth eventually led to complete occupation of arable land: it means however that further simulation results concerning sustainability and project action impacts cannot be compared with the present situation, particularly in Gabi where real land occupation has been complete for at least 40 years.

After the first cropping years, average yields are not strongly affected by land scarcity. Yields are significantly different between sites as determined by the model inputs and decline slowly from 4 to 5.5 q/ha at $t = 10$ to 3.5 to 4.5q/ha at $t = 60$. This resilience cannot be explained by a permanent compensation of the old fields' fertility loss by new fertile inclusions because land is already saturated in Zermou. It means that local farming systems are resilient enough in all the three sites to maintain yields, but with low yield values. It allows the simulated population of the three sites to maintain its food security throughout the simulation period. As people already live in these sites, it gives confidence on the model realism. Analyzing the evolution of the ratio between the annual consumption per villager and the income equivalent from the three main activities and the livestock capital, one can notice that if the Gabi site population food ratio even strongly increase, the consumption ratio remains stable for Fakara and slightly declining for Zermou, making them more prone to food shortage crises.

The gender income ratio evolution shows the difficulty for women to sustain while having no access to economic activities for the Gabi and the Zermou sites. The Fakara site ratio slightly recovers over time due to female access to garden production gains¹³. The Gini coefficients¹⁴ established at family and individual levels suggest another limitation of the systems: inequalities between families and within families grow, meaning that economic discrimination grows along the 60 years of simulation.

4.3 Projects implementation: successes and failures

4.3.1 A low success mainly due to a poor saving capacity

The Figure 3 shows the impact of the project interventions on the population and related effects. Both Figure 3.1 and Figure 3.3 show a generation effect which suggests the strong relationship between the capacity for savings and the manpower: it supposes that having a higher manpower per capita ratio allows a household head to save more. However, Figure 3.3 suggests that the saved quantity is strongly linked to the capacity of a site to procure enough excess yield for savings: the Zermou population is unable to create enough production to both feed people and save millet. Therefore, and despite the hope of development operators to implement warrantage all over the country, the success of this intervention should be considered as highly determined by the local capacity for millet production.

Inorganic fertilizers use shows strong differences between the three sites : whatever the sites, fertilizer use remains very low, with less than 10% of farmers using it (Figure 3.2) and less than 4% of the total surface (Figure 3.4). Gabi and Fakara populations show similar behavior regarding the inorganic fertilizers use, but at different levels: as far as they maintain a high manpower per capita ratio (between $t=5$ until $t=12$ for Fakara and $t=20$ for Gabi) allowing them to easily clear new fields and to weed cropped fields, farmers are not using inorganic fertilizers¹⁵, suggesting that gains from activities other than farming are used for more promising purposes, such as migration. Thereafter, one can observe that the proportion of population using fertilizer and fertilized land reach a higher value in Fakara than in Gabi due to an initial lower fertility level. In a simulated context of no land saturation, the Gabi population appears less concerned by inorganic fertilizers and on less surfaces. One can then suppose that inorganic fertilizers are not attractive wherever free and fertile land is still easy to acquire. Present-day figures for a full-saturated Gabi site show that $2/3$ of the farmers actually use

¹³ For the case of Fakara, women manage the gardening activity, which explains the faster redistribution of the income after the generalization of the activity after the year 18, as shown in figure 3.6.

¹⁴ For n slices, the coefficient is obtained by the Brown formula (we have chosen $n = 5$ as used in demographic studies):
$$G = 1 - \sum_{k=0}^{k=n-1} (X_{k+1} - X_k)(Y_{k+1} + Y_k) ; X_k: \text{the income of the } k \text{ slice}; Y_k: \text{the size of the } k \text{ slice (Dorfman, 1979)}.$$

¹⁵ The initial high values are due to the first trials they manage to get some personal experience with the use of fertilizers.

inorganic fertilizers. Therefore, simulating present time inorganic fertilizers use would require implementing a full-saturated context in Gabi.

Zermou farmers show a different behaviour at the start of simulations, largely due to their particular strategy of fields extension to compensate for their lower yields. The first 25 years shows that, as long as the manpower/population ratio remains favorable and new fields can still be cleared, one observes a growing use of inorganic fertilizers. At the time land is fully occupied, reducing drastically the interest for farming, fertilizer use declines until a quasi-zero level.

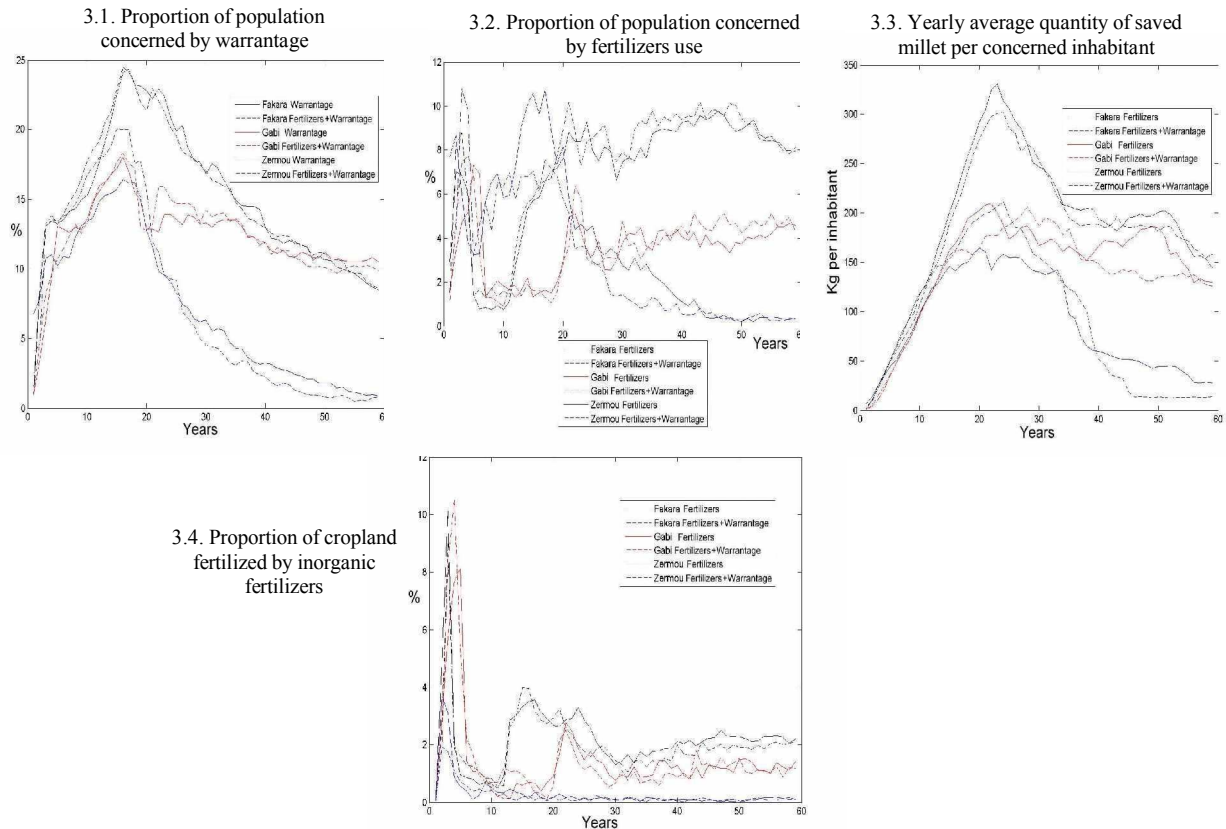


Figure 3. Comparison between the three sites of simulation output means concerning development action impacts

4.3.2 Two development proposals targeting different groups of populations

Dashed curves for the simulation outputs of the combined actions scenario shows that there is no synergy between the warrantage and inorganic fertilizers use strategy, suggesting that the logics and even the population concerned by the two activities may be distinct. Exploring the characteristics of the population involved in the two proposals helps to identify the most determining characteristics for involvement in projects. As fertilizer and warrantage users at Zermou are too few, the analysis of the involved population concerns only the sites of Gabi and Fakara. Inorganic fertilizers users all had in common a higher manpower per capita ratio at family level but a lower land per capita ratio and a lower livestock per land ratio than the average population. They can be split into two groups (Table 4):

- “Small young disadvantaged but growing families”: their average lineage value is low (1.6 vs. 2.8 for the whole population), suggesting that the most interested people are the ones who were disadvantaged in the land access due to social tenure discriminations. Families are small and thereby, manpower and owned land is low. The head of the family is younger than average (35 years-old vs. 43). However, the higher manpower/population ratio allows the family to sustain by diversifying income sources (millet fields, migration and after a few years, livestock sales and gardening). It also allows the use of inorganic fertilizers by succeeding in all the millet cropping cycle steps, particularly the related higher manpower requirement for weeding. Inorganic fertilizer use seems to be a way to compensate the low level of land and livestock manure. This group represents at most of 30% of inorganic fertilizer users around the 15th year and then declines, eventually disappearing around the 40th year of the simulation.
- “Large old but shrinking families” : the family head is far older than average (61 years-old vs. 43). Because of the non-cooperative family organization (Saqualli, 2006), elder children leave once they get married, taking with them some parts of the livestock and their manpower. The high income per capita ratio, with a

high livestock per capita ratio, allows mobilizing enough funds to compensate for the declining manpower ratio. The size of this group at the start of the simulations is higher by 25% in the scenario combining both warrantage and inorganic fertilizers compared to the scenario with only inorganic fertilizers.

Table 4. Indicators and ratio comparison between project user families and the average population

| Family characteristics compared to the average population | Inorganic fertilizers using population | | | | Warrantage using population | |
|---|--|---|------|---|-----------------------------|---|
| | (i) | Δ | (ii) | Δ | (i) | Δ |
| Family head age | - | ↑ | ++ | ↑ | + | ↑ |
| Lineage | -- | ↓ | / | ⇒ | ++ | ⇒ |
| Family Size | - | ↑ | + | ↓ | ++ | ⇒ |
| Manpower | - | ⇒ | / | ↓ | ++ | ⇒ |
| Land size | - | ↑ | ++ | ⇒ | + | ↑ |
| Livestock | -- | ⇒ | + | ⇒ | ++ | ↑ |
| Income per capita | / | ⇒ | + | ⇒ | + | ↑ |
| Livestock per capita | - | ↓ | - | ↓ | ++ | ↑ |
| Land per capita | - | ⇒ | - | ↑ | + | ↑ |
| Manpower per capita | + | ↑ | + | ↓ | + | ⇒ |
| Manpower per cropped surface | / | ↑ | - | ↓ | ++ | ⇒ |
| Livestock per cropped surface | - | ⇒ | - | ⇒ | + | ↑ |

(i) --: -25% and less; -: -10 to -25%; /: ±10%; +: 10 to 25%; ++: 25% and more
 ↓: -25%; ⇒ ±25%; ↑: +25%

Anyhow, inorganic fertilizers seem to be interesting only for families in transition: they cannot be used by the poorest as it is too expensive, and the wealthiest can use other and cheaper assets, particularly manpower and livestock in a context where land is still not a constraint.

For the two sites, warrantage users are members of a unique group that can be described as “large better-settled families” : their average lineage value is quite high (3.2 vs. 2.8), and the family head is somewhat older than average (48 years-old vs. 43). Families are big and growing, with a higher amount of young adults than average and consequently, manpower and owned land are higher as well. Warrantage seems to be an alternative to livestock as an income saving tool, but only families that are able to maintain a saving capacity get involved.

5 Discussion and conclusion

One can then estimate that the three sites show different trajectories based on their predefined potentialities: these last influence the demographic growth and even more the manpower ratio, but also the involvement in farming activities: Zermou is disadvantaged in the continuous run between family needs and available manpower. Therefore, the question should concern the long-term sustainability of the settlement and colonization process, when the three sites show a decline in income per capita.

Social and environmental indicators suggest the sustainability but also the fragility of such systems in the simulated conditions. However, the temporal scale has to be redefined particularly regarding the case of Gabi: the present day situation shows a complete saturation of the available arable land, because of a longer and more intense period of field extension. It means that the fragility suggested by these simulated indicators should be even higher in the real situations.

As a matter of fact, the success of both proposals is strongly defined by the local biophysical capacities to sustain village populations. Involvement in warrantage and inorganic fertilizer projects do concern only sites where millet savings for securization or intensification are possible, which is not the case for Zermou. Even so, success in the last two sites is in any case limited, with a greater impact of the warrantage proposal than the fertilizer one. These proposals actually require some investment capacity that few people do have in Fakara and Gabi. This capacity is largely conditioned by each family food requirement in relation to its manpower in a context where land is still available. Only a maximum of 25% of the population engages in a project proposal: warrantage in Fakara, only during periods when enough manpower was available. In the fertile site of Gabi, a land intensification proposal does not have a large success, as long as new fertile land remains available. However, due to the limited temporal scale, simulations do not provide information upon a possible intensification process in a context of land scarcity. Therefore, one should consider these proposals as a potential support tool for a limited part of the population to go beyond the survival level, but not as a poverty-alleviation panacea.

Therefore, this methodology has underlined that:

- Development projects often focus on the costs/advantages of a development proposal, which can be considered as the characteristics of an offer in an economic exchange, assuming that proposing such proposal will generate its own demand. Meanwhile, modeling one society reaction to new economic opportunities, by redefining this demand pattern, i.e. the distribution of assets within families, shows that this demand conditions the “market” size for such proposals.

- Development interventions have various successes according to the household types and to the considered area: future development proposals in Nigerien Sahel should resort to a diverse panel of proposals and never base their future plannings on the assumption that a proposal, whatever its intrinsic quality, will expand all over the country. Unfortunately, this fundraiser-oriented marketing approach is in use in many development-planning programs, often suggesting that a proposal will succeed in a whole country, when data and informations are based on one local experience. This simulation tool, by suggesting the strong impact of local social and biophysical factors and their local variability and distribution, allows advocating for a new marketing approach, focusing on the local and variable population demand.

This work should be understood as a step-by-step construction. As defined from the field observations, some factors were eluded in the modeling process:

- Labor and land markets were not implemented: While land markets are still quasi totally absent in the sites of Zermou and Fakara, they do exist in Gabi, particularly for irrigable places, which is obvious in a context of land saturation that we did not implement. There are still quasi no labor markets in Zermou, but Tahirou & Sanders (2006) and our own observations in Fakara suggest that this activity, while quasi-absent in the 90's (Ada & Rockström, 1993; Loireau-Delabre, 1998; Mounkaïla, 2003), have grown very rapidly.
- While literature often defined the Fulani ratio being around 10% of the local population, figures from Barbier & Hazell (2000) suggests that they may reach around one third of the total population in the Fakara. As they have a different land and livestock use mode, including their presence on a model may transform outputs and further prospectives.
- Yamba (2004) has noticed a generalization of the divorce institution. Since no data is actually available at the national level, the phenomenon was not modeled but we assume that this factor could have a strong impact as women resort to divorce at least once in a lifetime bringing with them some assets, particularly small livestock. Therefore, this institution can provide more independence to the women-driven local economy and more variability in the accumulation processes at family level (Turner, 1999).

This model was determined by the initial hypothesis that the present time evolution of any farming system is better understood by integrating the system history and inertia¹⁶: To start the village simulation from its foundation is more relevant than rebuilding a general tenure or family pattern as “a copy” of an observed situation, because the past social dynamics are also included. Whereas one can find less than 60 year old villages in the Zermou or the Fakara sites, none can be found in the site of Gabi. Therefore, because their dynamics are older than the duration of the simulation period (60 years), some Nigerien areas, as Gabi, cannot be well-simulated: the simulated outputs may well represent what could have been observed at the time, but do no longer correspond to the present time. If we suppose that the fecundity are quite equivalent for the three sites, it shows that the dynamics in the latter are older and that this difference should be taken in account: the history of the land conquest should be included to understand the present time dynamics of farming systems in Niger.

New phenomena may appear in simulations longer than the 60 years we implemented, as land scarcity will then operate for the different sites. However, pursuing the simulation beyond the 60 years bound may encounter practical simulation limitations as simulation time requirements are exponential. In any case, pursuing simulation by extending the scenario without offering some adaptation processes to the population will obviously show population and environmental crashes in a Malthusian approach. New simulation approaches that include social evolutions may bridge the gap between sociological and agro-economic analyses and thereby open the vision of different futures of these societies.

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¹⁶ I.e. the resilience of various phenomena (demography, agro-ecology) putting apart any qualitative judgement

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