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Abstract. This article presents the results of a methodology combining an extensive fieldwork, a formalization of field-based individual rules and norms into an agent-based model and the implementation of scenarios analyzing the effects of social and agro-ecological constraints on rural farmers through the study of three different sites in Nigerien Sahel. Two family transition processes are here tested, following field observations and literature-based hypotheses: family organizations can evolve between a patriarchal mode and a non-cooperative one because of family income redistribution tensions. Family inheritance systems can shift between a "customary" mode and a “local Muslim” one through family land availability tensions. Our results show that both agro-ecological and socio-economic characteristics determine the simulated family type distribution and consequently the allocation of resources. Results from simulations with no evolution processes show that villages specialize themselves on different economic activities according to natural resources: An intensification gradient is observed from the most favored site, with more local productions and improved ecological indicators, to the less-favored one, with a growing proportion of the population wealth coming from migration remittances and “off-shore” livestock. Once introducing such processes, the differentiation also occurs within the population level, subdividing it into specializing groups according to their size, their assets and their social status. Emerging individualistic family types increase the village populations' robustness through different and site-specific evolutions.

Keywords: individual agent-based modeling, economic assets social distribution, family transition processes, inheritance, family organization

1 Introduction

Since the crises of the 70’s and 80’s, the Sahel has become the focus of strong debates on the importance of social factors in the evolution of systems of activities and farming systems. More precisely and as systems of activities in Sahelian Niger are based on small farms and families, the evolutions of this last scale are considered by several scholars (Stone *et al.*, 1990; Wiggins,1995; Stone & Downum, 1999) as crucial determinants of the evolution of such systems, along more environmental ones that are the basis of the "desertification" concept (Aubreville, 1949; Adams & Mortimore, 1997). Several scholars have acknowledged the population capacity to adapt the rules of access to production assets and thereby the organization of the systems of activities they use. In particular, the link between demography, social structure and resources has been noticed as far back as 1956 (Davis & Blake, 1956).

These anticipating adaptation processes are already taking place in Nigerien Sahel: inheritance, family organization, land tenure, social and symbolic references are evolving, because of economic pressures on individuals, families, and communities. Milleville & Serpantié (1994), Lambin *et al.* (2001) Reenberg (2001) and Tappan & McGahuey (2007) among others have all highlighted the major importance of social factors in farming system evolution analyses. Grégoire (1986), Luxereau & Roussel (1997), Olivier de Sardan (2003), all referring to the Sahelian part of Niger, have suggested two major, village-level social factors to consider as the main pathways for local farming system evolutions:

Family organizations: All the investigated literature that concerns local family evolutions described the average family at the end of the 19th century as enlarged and quite strictly hierarchized. The father was ruling the whole family, including servants and slaves, as one single consistent exploitation, management and decision unit. Such families may be defined as enlarged (because they group several generations that are not allowed to leave the family unit) and unitary (because members should obey one decision unit, i.e. the family head). Actually, this unit was not fully independent: insecurity was forcing enlarged families to act as a group against foreigners, usually under the rule of the old aristocracy or the rising warlords. Meanwhile, the French political pacification at the beginning of the 20th century opened both the access to land in the Nigerien Sahel and to external jobs in the Gulf of Guinea. Migrations and more individualistic behaviors trajectories multiplied (Timera, 2001) and undermined the hierarchy foundations, rendering more and more difficult the justification of wealth and asset concentration in the hands of a single person, the head of the enlarged household. We therefore hypothesize that this led to an explosion of the family organization as theorized by Boserup (1965 pp. 316-346): The formerly dominant unitary patriarchal family archetype was partly replaced by a mononuclear, multi-activity and multi-decision-led family type, better adapted to economic, agroecological and social shocks as described and simulated in Saqalli (2006).Actually, our census in three sites of the Nigerien Sahel reports the presence of both types but in different proportions depending on the site[1]. It means that such a shift was not absolute but variable depending on site characteristics, but also that this shift has occurred in all the Nigerien Sahel. Such dismantlement of the family structure is actually described by an extensive literature regarding various sites in Nigerien Sahel or the neighboring countries[2]:.

Inheritance modes: In the 19th century and because of the need for powerful and enlarged families facing insecurity at this time, practices were oriented to maintain the power of the lineage more than equity. The legitimacy was then based on the "custom"[3]. Therefore, the so-called "customary" inheritance mode was based on the entire transfer of all the land and assets of the father to his eldest son. It is considered to have been the major inheritance system throughout the Sahelian part of the country up to the beginning of the 20th century (Raynaut *et al.* 1997). It remains dominant in large parts of Nigerien Sahel, mostly in northern and less densely populated zones and where land pressure is still low (Vanderlinden, 1998). As described by Luxereau & Roussel (1997), Tiffen (2003) and Yamba (2004), due to the decrease of available land, this inheritance mode has shifted in several densely populated and land-saturated areas of Niger to a local version of the Muslim inheritance system[4]: land and livestock are equally shared only between direct heirs but gender specifically (i.e. female-owned livestock is shared between female heirs and male-owned livestock and land between male heirs), collateral relatives receiving a share only in the case of no living adult children[5]. This adaptation can therefore be considered as a pathway for farming systems transition because of its catalytic reduction effect on average available land per family, without blatantly confronting the Muslim official principles that are even stronger in the present time than one century ago. One should underline the effects of such an evolution: a reduction of the average arable surface per family by including the cadets into the land allocation system means thereby that families are more rapidly forced to choose whether to involve more in the agriculture production or to diversify into external activities. It can be considered as a strong incentive for either intensification along a Boserupian process or a disintensification one as described by Conelly (1994).

We then adopt these two processes as the first driving media on which families may evolve in Sahelian Niger and thereby the related farming systems. Therefore, our objective is to develop answers on the following questions: What are therefore the long-term effects of such processes for the concerned families and farming systems? Do these effects are equivalent for all Nigerien Sahel?

Local history should be included to characterize one village evolution perspective: the complex structure of Nigérien farming systems cannot be considered as “traditional” but as the result of political and historical evolving stakes. Therefore, farming system evolution modeling should be temporally based and determined not on the present-time situation but on the initial conditions, i.e. the foundation of the village. Because such processes are conditioned and determined by both socio-economic and agro-ecological factors acting on a combined and intricate manner, it is irrelevant to focus on one side only. Therefore, for such a research, one should consider looking for a tool that can put in balance all the different economic and production activities of a Sahelian village but also all the factors that condition such activities, whatever the disciplines they belong. We consider that such a tool can be a model based on individuals, in order to avoid household oversimplifications. Meanwhile, a model cannot intrinsically and practically conceive all the possible evolutions of a society. Scenarios and hypotheses have to be built. Comparing the outputs of the four combinations of these two factors to determine the best theoretical “solution” is not relevant because history shows that these transitions have already existed, which means that no comparison can be made between simulation results and present time situations, as a confidence building step for a modeling tool. The analysis is therefore based on a comparison of scenarios with or without evolution factors.

Our purpose is then to analyze the effects of such transition pathways in several rural Nigerien Sahelian villages with different levels of natural resource endowment and socio-economic opportunities and constraints. The purpose of the present article is to analyze the long-term impacts on village societies and farming systems of the two agro-ecologically originated but socially driven forces we described above, i.e. family organization and inheritance mode transitions.

[1] 76% of our sample in Fakara (Tillabery region, southwestern Niger) belongs to the non-cooperative mononuclear type, 59% for Gabi (Maradi region, south central Niger), 69% for Zermou (Zinder region, southeastern Niger).

[2] The disintegration of the enlarged family was noticed as far as 1914 for the Zarmaganda (Olivier de Sardan, 2003 p. 246)

[3] Islam values were less strong in Niger at the beginning of the 20th century and many anthropological works have shown the resilience of animist values, references & ceremonies (for instance the *bori* or possession by djinns) that however are presently declining.

[4] Religion is the only counterforce to tradition to allow one modification of this very strategic rule of inheritance.

[5] One should notice that the main difference between the written and official Muslim law and reality is that almost all women do not officially own fields, largely due to the tricks men use to avoid female land inheritance. It can happen that some women officially inherit some pieces of land, but the social pressure forces them anyway to “delegate” the management to some brothers. This phenomenon is actually widespread in all Muslim Africa. Cf. “harem and cousins” by Tillon (1966).

2 Methodology

2.1 A Field & Modeling Process

The whole work of model construction can be seen as an iteration of ‘there and back’s’ between field working and modeling as exposed by Drogoul *et al.* (2000). We based our analysis on an already built empirical and KIDS agent-based model describing different village situations (Edmonds & Moss, 2005; Janssen & Ostrom, 2006). The selected ABM platform is CORMAS (Common Resources Management Agent-based System) developed by CIRAD (Bousquet *et al.*, 1998).
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) as well as the individual-centered model itself called, with relationships and dependencies between villagers (gender & rank as main factors of hierarchy in the family; lineage & individual and family wealth as the main factors at the village level) as well as their differentiated accesses to economic activities (agriculture, livestock keeping, seasonal migration, dry-season gardening). The SimSahel model was successfully used to assess the impacts of development proposals in Saqalli *et al.*, (2008). The behavior rules are based upon the translation of the investigations that were done on the three different survey sites, according to an interpretation process similar to that of Gladwin (1989) as cited by Huigen *et al.*, (2006). For the whole biophysical module (climatology, pedology et phyto-ecology) as well as for all functions that are not related with socio-anthropological logics of production means management (demography, price evolutions of non local products), rules and parameters are based upon the available published or unpublished literature[6]: The project that supported our research had collected extensive literature and data sets during the last 20 years in three sites of the Sahelian Niger, namely Zermou in the region of Zinder, Fakara in the region of Tillabery and Gabi in the region of Maradi. These sites represent three contrasted situations of the global rainfed agro pastoral zone of Niger along a gradient of scarcity and aridity from the best-endowed site of Gabi, then Fakara to the worst endowed Zermou (Table 1).

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 Variability: [70-525 mm]	Mean: 450 mm Variability: [180-675 mm]	Mean: 550 mm Variability: [275-775 mm]
Initial soil fertility	Poor in average	Average in average	Good in average
Soil arability proportion (%°)	Valley: good 0.1 Plain: average 69.9 Stony hills: unsuitable 30.0	Valley: good 3.9 Plain: average 79.6 Plateaus: unsuitable 16.5	Valley: good 18.1 Plain: average 60.0 Hills: poor 21.9
Migration impact on other activities	Gardening incompatible with migration	No competition between gardening & migration because of gender differentiation	Gardening compatible with migration
Migration constraints	Transport costs: 45 kFCFA Racket risks: 2%	Transport costs: 30 kFCFA Racket risks: 1%	Transport costs: 5 kFCFA Racket risks: 0,5%
Main ethnicity	Hausa	Zarma	Hausa
Present time family type	Mononuclear	Mononuclear	Mononuclear
Women activity	Sheep raising	Sheep raising & gardening	Sheep raising
Men activity	Farming, migration & gardening	Farming & migration	Farming, migration & gardening
Present time inheritance system[7]	Local traditional	Local traditional	Local Muslim

2.2 Building a model on family evolutions based on rural transition social driven pressures

This first implemented transition process, related to the family organization, was introduced in the model by building a family attribute called "antiClan tension" or Tac, initially equal to zero at the family creation step. It then evolves according to two effects. For all the adult family members who are not family heads or first heirs, having to give back part of the gain generated in the activity of which he/she was the manager (migrant coming back from migration, gardener bringing back the gains from his/her garden), in the hands of the family head increases the Tac. Tac also rises at every new land extension, underlining the impact of this extension in the

[6] Reports & documents from development or research agencies, MSc & PhD research dissertations
[7] The customary so-called traditional mode is considered as favoring one of the male descents, usually the elder, by giving him quite 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.

explosion of families[8]. In the two cases, the evolution is simulated as follows: for each event having an impact as described above: Tac (t+1) = Tac (t) + 5 (1)
The family can shift from the unitary mode towards the non-cooperative one if: Tac (t) > 100* MoF (t) (2)
If this condition is met, the marriage of a young groom means leaving his family and create his own on newly occupied lands. This new family has its own initial value Tac equal to 0 as an initially unitary family. A part of the gains stays in the hand of production activity managers and food distribution processes within the family are shortened but weakened as described in Table 2.

Table 2. The simulated characteristics of the two simulated family structures

	Unitary Family Structure	Non Cooperative Family Structure
Family structure	Married sons remain at home;	Married sons leave home and build new families
Condition for marriage	The family head, most often the father, pay the dowry.	The « fiancé » pay the dowry.
Sharing food	All income is given to the head of the family, who shares them among members[9]. Therefore, the family balance is equal to zero when he dies.	A « family granary » as an account to share to fulfill the demands of family members [10]. Family members' balances are maintained whatever happens to the head of the family.
Availability for seasonal migration	The head of the family defines his manpower needs for each millet cycle stage. Only him can allow a young male family member to leave earlier for migration	A young male family member can leave for migration during the millet-cropping season if there is still an elder with a higher rank staying at home.
Fields extension	Families do not explode and cropland expands based on family needs	The direct heir has all the inheritance; others have to settle somewhere else.

The second transition process considers that the land availability constraint, growing with the difficulty of finding new lands, brings a growing "frustration" of the non-heirs. This frustration is simulated through a family attribute called "land tenure tension" Tf, initially equal to zero at the family creation, that evolves at every failure in the search of new empty lands, as follows: Tf (t+1) = Tf (t) + 5. (3)
This value can grow rapidly according to the number of attempts: more the family is big and grows rapidly, more this Tf value increase quickly. The family can adopt a "Muslim" inheritance mode if: Tf (t) > 200* MoF (t) (4)
This procedure takes effect only after the death of the head of the family. It then imposes the sharing of lands and of livestock according to this "local Muslim" rules, i.e. all fields are equally shared between the male heirs of the head of the family (brothers and sons) while livestock is shared between male heirs for two thirds and female heirs for one third.
It is important to note that the simulated social evolutions are reversible and that certain family types may reappear. The calibration of these two processes has been jointly carried out for the three sites according to the collected information and literature. Twenty simulations of each of the two scenarios have been assessed.
Comparing the simulation outputs of these social change procedures with the present-day situation to determine the best theoretical "solution" is not relevant because literature shows that these transitions have already occurred, hence a poor fit between model results and reality for a given combination of factors does not invalidate the fact that this combination may have been relevant in the past. The comparison between simulation results of our model and present time situations can therefore not be used as a confidence-building step. The analysis is therefore based on a comparison of scenarios with or without evolution factors. Meanwhile, the model has successfully passed a confidence building procedure by comparing literature data on demography and land use with simulation results (Saqalli *et al.*, 2008). Therefore, we compare the results of two scenarios:

- The first one is the "No-Evolution Scenario", where farming systems and populations evolve in the absence of family organization and inheritance changes as a reference level for comparative purpose.
- The second one is the "Evolution Scenario" where both family organization and inheritance systems can change according to the rules described above.

Simulations begin with the foundation of the village by families that belong to family customary organizations and traditional inheritance modes. The model scenarios are implemented on one-century long simulations. The model initialization is realized as follows: at t=1 fifty villager Agents of various ages and gender-defined and 100 livestock head Objects, with one third of every species, appear in the village territory. We first analyze the evolution of the three sites over a 100-year period according to the "No-Evolution" Scenario to compare thereafter with the results of the "Evolution" scenario. The presented results are selected for the purpose of

[8] Nearly all the villages where local history was investigated have witnessed a conflict between brothers or cousins within the "reigning" family during the 20's to 40's era. A possibility to settle alone on empty lands can be considered as a permanent attraction for villagers; we included this attraction at family level because more lands because of field expansion means more economic power of the family head and more work for the family members while they may get this new land for themselves.
[9] Therefore, all gardening incomes remains in women incomes in the non cooperative scenario whereas, in the unitary scenario, even this money goes to the balance of the head of the family.
[10] Redistribution is limited to dependants of each active person in the family. It also means that a person who cannot afford expenses for all his/her dependants can "ask" the head of he family or any person with a higher rank within the family for support, only for that particular time step.

illustrating the main divergences between scenarios. The selected variables do not stabilize themselves over time because of the population growth that maintains itself throughout a simulation.

3 Results

We compare firstly the evolution of the three sites over 100 years in the situation in the scenarios without family organization changes. It permits us to envisage afterwards the comparison of these results with the scenarios that include the simulated social changes. The presented results are selected for illustrating the main evolution divergences between scenarios. The selected variables do not stabilize themselves over time because of the population growth that maintains itself throughout a simulation.

3.1 Non-evolution scenarios: a degradation impact following agro-ecological and economical conditions

The results shown in Table 3 (appendix) are the simulation outputs of a scenario in which no family organization or inheritance mode evolutions are considered, with only unitary and patriarchal families and a system of customary inheritance.
The three population sites strongly raise, by a factor 11 in the site of Zermou, the least agro-ecologically and socio-economically favored site, while Gabi, the most favored site, reaches a factor 32 (Table 3 line D).. The site characteristics have therefore a noticeable effect on the simulated population growth. The simulated constraints decrease along a north to south Zermou-Fakara-Gabi gradient and thereby their consequence on the related simulated societies:
The territory of each simulated site is progressively occupied, in less than 25 years for Zermou as opposed to nearly 100 years for the Fakara and Gabi sites (Table 3 line A), because the lower soil fertility in Zermou (see Table 2) implies rapid yield decline forcing the population to more quickly expand their fields, while Fakara and Gabi do not experience such race for land. At the three sites, the simulated population continues to rise and there is no collapse of agricultural production even after the total occupation of arable lands, despite the decline of soil fertility and vegetation, but a continued decline up to a minimum and stable level. The simulated fertility-regenerating procedures, which are the 1-year fallow regeneration process[11] and the manure supply from herds, seem to play a real effect on the fertility decline. Other non-agricultural and thereby rain-independent factors (migration, gardening but also partly livestock) help to support the populations' growths.
Agriculture appears less important in terms of income share than expected according to many scholars (Affholder, 1997; Breman *et al.*, 2001; Dreschel *et al.*, 2001)[12]. This activity, as the most sensitive to the agro-climatic conditions, declines more or less rapidly at the three sites after an initial peak. This peak is longer at the best site, namely Gabi (nearly for fifty years at $^2/_3$ of the village global income) in comparison with the most difficult site, namely Zermou (less than 10 years before declining). The decline extent is sensitive to the site factor as well: agriculture represents at t=] 75:100] 44% of the village income in Gabi and Fakara but drops to 25% in Zermou. Gardening does not compensate everywhere this decrease of local agriculture: this activity is nearly absent in Zermou, because of simulated agricultural reasons (the territory simulated in Zermou is nearly totally void of irrigable parcels) but also because of social ones: As indicated in Table 2, gardening in the Hausa sites of Zermou and Gabi is restricted to men, but the implemented impact of the distance to the Nigerian border for Zermou does not allow men to practice simultaneously gardening and migration, while it is possible for men in Gabi. Gardening does not take off until after land saturation, implying a manpower reallocation at the family level.
Simulated herds are progressively more and more cattle-dominated, that are in majority in transhumance during nine months of the year and therefore with little effects on local fertility transfers but also independent from the local pasture constraints. This cattle accumulation can therefore be considered as a way of "off-shore" savings[13]. Livestock keeping maintains itself all along simulations, whereas migration grows slowly at the three sites, reaching up to 45% of the total local income in Fakara. The gradient Gabi-Fakara-Zermou remains applicable for the irregularity of millet yields. An equivalent gradient appears for migration, because of the highest transportation cost and the higher racketing risk in Zermou (Table 2) but not for gardening, (because it is independent from rainfall) and livestock keeping (because of the "off-shore" effect on almost the totality of the herd, and thereby its quasi–independence from local conditions). Migration and livestock keeping, as extra-local activities, play therefore a role of compensators facing the local resource limitations.
This absence of collapse and the gradual decline of natural resources in the simulations are accompanied by the stagnation and even the reduction of local subsistence means per inhabitant: actually, the cropped surface per

[11] This process is implemented only for fields that were sowed but whose sowings failed and were therefore abandoned for a one-year fallow.

[12] See Niemeijer & Mazzucato (2002), Koning & Smaling (2005), Mortimore & Turner (2005) for a discussion on this gap.

[13] As the model is village-based, it does not take in account the question whether outside transhumance territories can accommodate such a cattle expansion, remembering the numerous incidents between herders and farmers observed in recent times (Turner, 1999)

inhabitant at the three sites declines over time (Table 3 line F). Only Gabi sees the average population income maintained and growing a little in this scenario (Table 3 line E). The site of Zermou maintains its livestock per inhabitant ratio, Fakara doubles it and Gabi sees it growing by a factor of 2.8 (Table 3 line G). These indicators altogether suggest that population and natural resources of these three sites as they are implemented jointly evolve but at a rate which depends on the initial conditions of each site.
This village scenario induces a rise in social inequalities. The income difference between men and women grows at the three sites (Table 3 line H). The site of Fakara presents the weakest growth of this inequality, mainly because women are the managers and the first recipients of the gardening activity. One can, however, wonder about a possible future appropriation by men of this activity if it becomes profitable, which would counter-balance the present-time male Zarma contempt for this activity.
The Gini coefficient[14] calculated between families along the simulation from the mean values of the repetitions (Table 3 line I) underlines the social differentiation between the families, in particular in Fakara, as an intermediate zone where differentiation is easier between families compared to Gabi where everybody can have quite good income and to Zermou where everybody suffers from poor yields and low gains.
Finally, the standard-errors show the growing vulnerability of these simulated systems: the standard-errors between simulations of the population (Table 3 line D) increase according to the gradient Gabi-Fakara-Zermou, indicating a higher potential vulnerability of the population of Zermou facing climatic and migration risks and costs. The inter-annual coefficient of variation between simulations, calculated from the average annual figures, has an average value of 2.15 in Zermou, 1.59 for Fakara and 0.78 for Gabi over that last 10 years (] 90: 100]).

Thus, the unitary family organization allows the distribution of activities to evolve when local resources become limited because of land saturation and/or degradation. This evolution favors external activities, particularly for the least favored site. The villagers' economic situation is more and more limited and fragile, but does not collapse. This last point is important: it means that building a model where no cognitive and complicated rules are implemented but where combining different economic activities at the family and individual levels is possible, allows a shift of all or a part of the population from one activity to another to maintain or at least limit the decline of the income because of local resources decline. The three sites seem therefore to "specialize" themselves in one activity amongst the alternative activities from millet agriculture: migration in Fakara, gardening for Gabi and livestock keeping in Zermou.

3.2 Introducing social evolutions: family shifts as accelerators of farming system evolutions

Results of the previous scenario are here compared with the simulation results of a scenario in which families can evolve according to the social rules established by the modeling methodology.

Family evolutions: same social rules but different contexts creating specific social stratifications. Families multiplied themselves at all sites through the "explosion" of once unitary families due to the inheritance and family organization rules we implemented, which means that the breakup of the unitary family dilutes and alleviates these tensions. Thus, we find in Zermou 104.5 families on average vs. 9.7 in the "No-Evolution" scenario at t=] 75:100], 117.4 families vs. 7.7 in Gabi and 204.5 families vs. 8.4 in Fakara! As Fakara presents the particularity of restricting the gardening activity to women and thereby creating another source of "frustration", the social "frustration" indicator Tac increases more rapidly at this site and Unitary families disappear in Fakara five years earlier than at the two other sites (Figure 1.3 to compare with figures 1.1 & 1.5). Moreover, the extent of this shift is far more important in Fakara, reducing the part of Unitary Families with a Customary Inheritance (UFCIS) to less than 5% of the number of families, but 19% of the total population. The Non-Cooperative Families with a Customary Inheritance (NCFCIS) become dominant reaching up to 59% of all families and 52% of the village population (Figure 1.4). The arable land saturation is slower than in the "No-Evolution" scenario can be seen from a comparison between lines A of Table 3 and 2. Consequently, the shift towards the local Muslim inheritance mode remains limited. At the two other sites, with a more rapid arable land saturation, the Non-Cooperative & "local Muslim" Inheritance Families (NCFMIS) become dominant in the number of families and even in the village population for Gabi (figures 1.5 & 1.6).
A family type unobserved during field investigations appears in simulations at the three sites: the Unitary Family with the "local Muslim" Inheritance (UFMIS). It occurs in case of land-limited and little multi-active families. Paradoxically, it is the site of Gabi, with more facilities for multi-activity (large irrigable land availability and cheaper seasonal migration), that maintains a more important proportion of such unitary families, reaching more than 20% (Figure 1.4) against 6% in Zermou (Figure 1.1) and 3% in Fakara. This development in Gabi could be explained by the fact that economic activities remain in the hands of the men, who can combine gardening and

[14] For n slices, the coefficient is obtained by the Brown formula (Dorfman, 1979). 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: the income of the k slice; Y_k: the income of the k slice.

migration thanks to the proximity of the border (Table 2), which allows the unitary organization to remain. Paradoxically, this group appears after the NCFMIS at the three sites rather than before these. They may originate from formerly UFCIS families but also from formerly NCFMIS having evolved directly into UFMIS, in the case of the young families having many young children and being unable to develop yet some activities other than the ones managed by the head of the family. In order to corroborate this appearance, one may notice that in urban and semi-urban areas of the Maradi region where Gabi is located, the development of a new middle-class of traders, called the "izalah", rather young families and very rigorous from a religious point of view[15], besides the old and big traders having established their fortune on clientele networks (Gregoire, 1986). We thereby suppose that the main reason why we did not observe such families in the investigated villages is that they have already shift in town, even if they still have and crop (and/or make crop) their fields in the village.

We obtain thus for each simulated site a different village organization (Figures 1.1, 1.3 & 1.5): the sites of Fakara and Zermou as they are implemented are almost totally composed of Non-Cooperative mononuclear families. They are shared in Zermou between Muslim inheritance families for the $^{2}/_{3}$ and customary inheritance families for $^{1}/_{3}$, while these proportions are inverted for Fakara. Finally, the Gabi population is shared between the two family types, unitary ($^{1}/_{3}$) and non-cooperative ($^{2}/_{3}$) and the two inheritance systems, customary ($^{1}/_{4}$) and Muslim ($^{3}/_{4}$). These proportions are important as they determine the proportion of "decision-makers" in the population (family heads only in the case of unitary families, a lot of adults in the case of non-cooperative families), whereas the proportions in terms of population, different from the family proportions because of the gap in family size between the family types, define the consequences of these decisions on the total population.

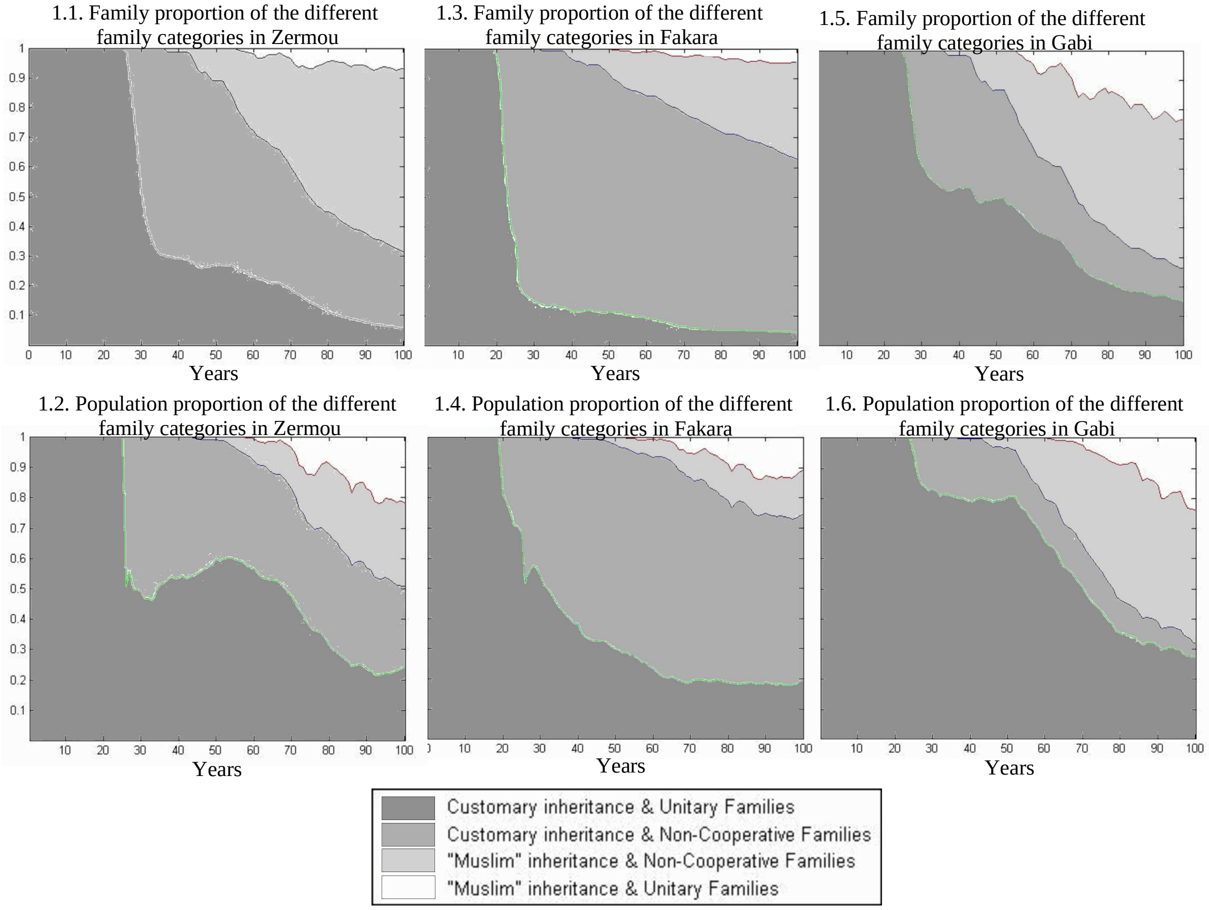

Figure 1. Proportions of the four different family categories & the different activities in each site

Production and sustainability at the village level. The new family type appearing has several impacts on the simulated village wealth (Table 4 Appendix):
As described in , the appearance of mononuclear families in Fakara slows the growth of the global population and of cultivated surfaces in a similar way than harsher agro-ecological and economic conditions (Table 3 & 4,

[15] This Islamic legitimacy allows them to limit their solidarity to the "zakat", the Muslim alms pillar, and therefore to be able to foresee their management and to free it from social and family contingencies.

line A & D), because of the increased delay for marriage (no intra-family support for the dowry and thereby restriction on farm settlements). Meanwhile, the two sites of Gabi and of Zermou are largely different: the absence of a significant difference between the two scenarios on land saturation and population can be explained first because the number of families is half of that of Fakara and second because about 50% of the population still belongs to unitary families that favor demographic growth. Moreover, one can consider that the discriminating effect of the new family organizations does not appear so much for these two sites: In Zermou, the monetary constraint is already strong enough for the "No-Evolution" scenario (livestock and income per capita are there already the smallest figures of the three sites); therefore, new family modes do not reduce much more the growth of the population. One can suppose as well that the monetary limits in Gabi that appear along the simulation with these new families are not strong enough at the family and individual level to slow down marriages in significant way and thereby the growth of the population. The average income in the "Evolution" scenario increases in the second half of the simulation at the three sites and more particularly in Gabi (Table 3 & 4, line E) compared to the "No-Evolution" scenario. The cropped surface per inhabitant doubles in Fakara in the "Evolution" scenario because of the lower population growth, which is logically not observed in Zermou or in Gabi (Table 3 & 4, line F). Inversely, if the livestock herd size per inhabitant is more than three times higher in Zermou and more than two times higher in Gabi in the "Evolution" scenario compared with the "No-Evolution" one, it grows in an equivalent manner for the two scenarios in Fakara (Table 3 & 4, line G).
Therefore, considering both income and livestock altogether, the three simulated sites experience a better level of wealth per capita. However, the most-favored and the less-favored sites get this improvement through livestock savings while the intermediate get this improvement thanks to a lowering of its population, because of a quicker orientation towards non-cooperative family modes.

In terms of environmental sustainability, although the land is more slowly colonized in the "Evolution" scenario, yields per hectare remain equivalent for both scenarios at the three implemented sites (Table 3 & 4, line B). The same is true for the vegetation cover in the two poorest sites, i.e. Zermou and Fakara (Table 3 & 4, line C). Gabi sees a slightly stronger decline in vegetation cover, related to a larger cultivated area and a higher livestock per inhabitant ratio. In terms of social sustainability, inequalities between families and between gender reduce in two sites: if the coefficients of variation of the gender inequality are significantly reduced in Zermou and for Fakara, they stay equivalent in Gabi (Table 3 & 4, line H). The inequality between families instead is higher in the "Evolution" scenario in Zermou and Gabi whereas it is significantly reduced in Fakara (Table 3 & 4, line I). Finally, the coefficients of variation between repetitions of several factors (population, income & surface appropriated per capita) are significantly lower for the three sites (Table 3 & 4, lines D, E & F) in the "Evolution" scenario, which means that the collapse risk of the income and/or of the population, following a drought for instance, are reduced thanks to these new family types. However, the livestock per inhabitant is less stable: the new scenario plays its stabilizing part on this factor only for Gabi whereas no difference appears for Fakara and the variability even increases in Zermou (Table 3 & 4, line G).

Therefore, the populations of the three sites as they are implemented seem to be more robust to the hazards of production activities. This new robustness, together with a higher average income per capita, seems in the case of Fakara to come from a population reduction while it seems to be acquired by a clear increase of livestock in the case of the two other sites. However, in this case as well, it is necessary to consider the impacts of other activities (gardening & migration) in the analysis of the adaptation ways of the new families, in order to explain the economic connections between genders and between family types.

Activities and livestock distribution. The social differentiation does not translate into a significant change in the relative importance of the different activities at Zermou. Agriculture keeps declining to the benefit of livestock keeping and migration, the latter reaching about 72% of the average income, while gardening stays next to nothing.
However, a strong evolution at Zermou occurs towards small livestock. This goes together with a multiplication by 3.9 of the volume of this herd (939±89 TLU vs. 240±39 in the "No-Evolution" scenario over the last 25 years). One can notice the multiplication by 28 of the number of goats (254 vs. 9 in the "No-Evolution" scenario), the caprine herd thereby representing 33% of the total livestock vs. 5% in the "No-Evolution" scenario, without a particularly strong decline of the vegetation cover (Table 3 line C). This results from the new social rules introduced by this scenario, which leads to the multiplication of individual strategies of livestock accumulation, geared towards goat and sheep that are less expensive. One may notice that the average sheep herd in Zermou increases from 2 to 18 units with the "Evolution" scenario, that is to say an evolution in the same proportion than that of the number of families. With one sheep per family to slaughter every year for the Tabaski ceremony, it means that despite the explosion of families, one family out of five can fulfill its social chores, similar to the "No-Evolution" scenario. It is an interesting indicator of the economic viability of these

families. With a tripling of the number of cattle, this added livestock is nearly independent of local pastoral conditions, thanks to the transhumance.

The site of Fakara sees the income contribution of migration rising (66% of the average income over the last 25 years against 39% in the case of the "No-Evolution" scenario), reducing the parts of gardening, agriculture and livestock keeping. The volume of the Fakara herd stays stable (837 ± 98 TLU vs. 952 ± 87 in the case of the "No-Evolution" scenario), but the composition evolves strongly as well with a multiplication by 7.2 of the goats, and by 3.7 of the sheep. Finally, the Gabi activities also change but through a focus on local activities. Agriculture and gardening are maintained, with a slight extension of the latter. Migration passes from 26% of the average income to less than 6%, whereas livestock keeping reaches 29% vs. 2% in the "No-Evolution" scenario. This strong growth can be explained by the same but more intense shift as observed at the two other sites, i.e. a multiplication of the small ruminants: 611 sheep and 1910 goats vs. 11 sheep and 9 goats in the "No-Evolution" scenario on average over the last 25 years, increasing the proportion of small ruminants from 1% to 37% of the total. These small ruminants are characterized by a life cycle turnover far more rapid than that of cattle, allowing for an increase of the number of sales and of auto-consumption. As the small ruminants stay on the village territory, their higher numbers means a higher fertility transfer from grazing areas towards the cropped fields. The multiplication of families means that a more important part of the cattle herd does not leave for transhumance as well, as the model forces each family to keep in the village territory some cattle, thereby reinforcing the fertility transfer effect but also the pressure on grazing lands.

As a partial conclusion, at the three sites, livestock keeping seems to change its status from of an "off-shore" saving account to that of a locally used "remunerating" account, particularly for the most favored site of Gabi. If no evolution in terms of activity distribution appears at the least favored site of Zermou, migration becomes preponderant in Fakara, whereas it is livestock keeping and gardening that plays this role for Gabi.

Production & sustainability at the family type levels. Analyzing the differences in indicator values among the family types provides information on their differentiated reactions throughout the 100 years of simulation. Table 3 presents the average values over the last 25 years of several indicators for each family type.

It is not the same social types that benefit from a better income per capita in the three sites (Table 5 line A): If the gaps between the types stays small in Zermou, with a slight advantage for NCFCIS in a globally poor context, the UFCIS of the two other sites remains the poorest, which can be explained by a higher ratio between children and adults. On the other hand, the NCFMIS income per capita reaches double that of other groups for these two sites. A high level of income does not imply an important availability in fields or in livestock (Table 5 line C & E), but rather more efficient orientation of the available manpower. As a matter of fact, the modeling does not introduce any cognitive process in the individual or family manpower allocation between activities, because these are quite practically not competing for manpower in terms of time schedule (migration mainly occurs after harvesting times). It is the "natural" evolution in terms of manpower, population and land access of the various family types that determines this allocation. For example, the proportion of fields owned by the UFCIS always stays important even with a small population, because of their anteriority in the conquest of arable fields.

The social organization profiles of Zermou and of Fakara can therefore be explained by the historical succession of the family types (Figures 1.1 & 1.5): the eldest group, the UFCIS, is the most involved in agriculture, whereas the most recent, the UFMIS, is the most involved in migration (Table 5 lines J & L). This last group can be considered as quite "absents" of the village, reducing their involvement in local activities. The Gabi population is different: it is influenced by a highest proportion of the UFMIS and by a highest field availability, and in particular garden-suitable fields: as opposed to the two other sites, the UFMIS type in Gabi see a large part of its income coming from local productions (gardening and agriculture). Also, the NCFMIS are land-limited but have a more "efficient" manpower: because they are non-cooperative, they can orient themselves in a privileged manner towards gardening. The part of income coming from livestock keeping is hard to interpret because it is not entirely linked to the size of the herd but more likely to its turnover rate that is quicker for small ruminants. The part of these small ruminants is growing along an UFCIS-UFMIS-NCFCIS-NCFMIS gradient, which is compatible with the growing monetary constraints of these types of family (Figures 1.1, 1.3 & 1.5).

Thus, the interpretation of the relationships between family types and economic families may be uneasy to interpret because it is ruled by complex micro-interactions. However, the distribution of the chosen indicators highlights a differentiation between family types that looks like the strategies one can observe in the field: The Fakara and Zermou see their populations differentiate themselves into family groups strongly related to the succession of their appearance: the first arrived UFCIS maintain a strong agricultural involvement, as opposed to the last two groups, mainly orientated towards the external activities (migration and cattle keeping). On the other hand, higher suitable land availability in Gabi permits the maintenance of local activities for all family types, particularly thanks to gardening.

Table 5. Selected indicator mean values for the last quarter t=] 75-100] for the three sites for the "Evolution" scenario (Mean+standard deviation; n=20).

	Zermou				
	UFCIS	NCFCIS	NCFMIS	UFMIS	
Income per capita (in €)	4.7 ± 0.2	6.8 ± 0.3	5.4 ± 0.7	2.2 ± 0.3	A
Income proportion (%)	24.9 ± 0.9	33.2 ± 1.7	33.0 ± 4.2	9.0 ± 1.4	B
Livestock size per capita (in L.S.U. equiv.)	2.5 ± 0.7	0.7 ± 0.2	1.0 ± 0.4	1.2 ± 0.3	C
Livestock proportion (%)	47.6 ± 14.6	13.1 ± 2.3	22.3 ± 8.4	17.0 ± 4.7	D
Cropped surface per capita (in ha)	1.0 ± 0.02	0.9 ± 0.08	0.3 ± 0.02	0.6 ± 0.06	E
Cropped surface proportion (%)	38.8 ± 0.7	31.3 ± 2.7	11.2 ± 0.9	18.7 ± 1.7	F
Yields (q/ha)	3,4 ± 0.4	3,6 ± 0.3	4,0 ± 0.3	3,8 ± 0.2	G
Coef. Gini between families	0.75± 0.01	0.63± 0.03	0.61 ± 0.02	0.88± 0.01	H
Livestock keeping proportion in the income (%)	13 ± 3	5 ± 0.9	11 ± 2	6 ± 1.2	I
Migration proportion in the income (%)	52 ± 5	79 ± 8	67 ± 7	89 ± 9	J
Gardening proportion in the income (%)	2 ± 0.1	1 ± 0.1	4 ± 0.1	1 ± 0.1	K
Pearl millet agriculture proportion in the income (%)	33 ± 7	15 ± 2	17 ± 2	4 ± 1	L
	Fakara				
	UFCIS	NCFCIS	NCFMIS	UFMIS	
Income per capita (in €)	7.6 ± 0.2	12.5 ± 0.2	22.8 ± 0.8	12.3 ± 0.5	A
Income proportion (%)	11.0 ± 0.2	51.6 ± 0.7	26.1 ± 0.9	11.3 ± 0.4	B
Livestock size per capita (in L.S.U. equiv.)	0.5 ± 0.1	1.0 ± 0.3	0.7 ± 0.3	0.5 ± 0.2	C
Livestock proportion (%)	13,0 ± 1.8	65.7 ± 15.0	13,1 ± 4.2	8,2 ± 2.2	D
Cropped surface per capita (in ha)	0.9 ± 0.03	0.7 ± 0.02	0.6± 0.02	0.3 ± 0.02	E
Cropped surface proportion (%)	24.4 ± 0.1	57.7 ± 1.9	12.8 ± 2.1	5.1 ± 0.4	F
Yields (q/ha)	3.6 ± 0.3	4.2 ± 0.3	3.9 ± 0.2	3.7 ± 0.2	G
Coef. Gini between families	0.73± 0.01	0.63 ± 0.02	0.62 ± 0.03	0.90 ± 0.04	H
Livestock keeping proportion in the income (%)	7 ± 1	10 ± 2	10 ± 1	9 ± 2	I
Migration proportion in the income (%)	36 ± 2	52 ± 4	58 ± 4	69 ± 6	J
Gardening proportion in the income (%)	12 ± 2	8 ± 0.4	11 ± 2	6 ±0.6	K
Pearl millet agriculture proportion in the income (%)	45 ± 5	30 ± 3	21 ± 5	16 ± 2	L
	Gabi				
	UFCIS	NCFCIS	NCFMIS	UFMIS	
Income per capita (in €)	10.6 ± 0.7	14.5 ± 1.2	25.9 ± 2.9	17.0 ± 1.6	A
Income proportion (%)	15.2 ± 1.1	2.2 ± 0.2	65.1 ± 7.3	17.4 ± 1.7	B
Livestock size per capita (in L.S.U. equiv.)	1.6 ± 0.4	1.5 ± 0.5	2.2 ± 0.9	2.4 ± 0.7	C
Livestock proportion (%)	21.3 ± 3.1	02.1 ± 0.3	53.1 ± 15.0	23.3 ± 4.8	D
Cropped surface per capita (in ha)	0.2 ± 0.04	0.7 ± 0.24	0.4 ± 0.08	0.2 ± 0.03	E
Cropped surface proportion (%)	20.3 ± 3.3	6.5 ± 2.2	62.3 ± 11.5	10.9 ± 1.6	F
Yields (q/ha)	5.8 ± 0.7	8.1 ± 0.7	3.7 ± 0.3	3.5 ± 0.2	G
Coef. Gini between families	0.73 ± 0.01	0.59 ± 0.02	0.60 ± 0.02	0.81 ± 0.04	H
Livestock keeping proportion in the income (%)	13 ± 1.1	22 ± 2	15 ± 1.4	28 ± 3	I
Migration proportion in the income (%)	3 ± 0.4	14 ± 1	5 ± 1	17 ± 2	J
Gardening proportion in the income (%)	34 ± 2	22 ± 1	49 ± 3	21 ± 1	K
Pearl millet agriculture proportion in the income (%)	50 ± 2	42 ± 2	31 ± 2	34 ± 2	L

* Combined weed and shrub vegetation

4 Conclusion

Introducing social change processes in a social model generates social groups with differentiated behaviors: New social restrictions limit the intra-family support, which has for consequence to restrain more strongly the income sharing at the individual level to his/her close family network. It let a bigger reinvestment at the local level through small livestock keeping and gardening, but also a higher level of "adequacy" to local resources, via various "strategies" (lowering of the population for Fakara, creation of a class of "permanent" migrants for Zermou or a class of "gardeners" for Gabi). These strategies are different for every site but permit to increase the robustness of the society and to limit the degradation of the local environment. Moreover, as heads of non-cooperative families do not control their members anymore, there are more autonomous individuals in their choice of economic activities other than agriculture. As the gain from extra-agricultural activities is more important than from cropping, these groups of non-cooperative families have a higher level of income per capita. Finally, the history and the social origin of these groups do matter because it defines the final distribution of access to production assets between family types.

Thus, the introduction of social evolution factors (i.e. the inheritance mode and the family organization) induced changes that corroborate a Boserupian approach of farming transitions, but with a nuance regarding the potential extent of such changes. Even within these sites, each family and each individual does not have the same chances of development and strong divergences appear: the least favored site population "exports" its wealth outside the territory through cattle "off-shore" savings and does not experience any intensification; the intermediate site evolves towards a South African-style split of its population according to social origins between farming families

and migrant families. The most favored site population is the only one to intensify its practices (better integration of livestock keeping and more gardening).
Therefore, the model results permit to confirm that:

- It is possible to combine socio-anthropological and agro-ecological factors in a model. A validation is always complex and difficult but the reconstitution of collective and differentiated behaviors based on simple and empirical behavior rules underlines the interest of such Agent-based modeling methodologies for analyzing the interactions between social and farming systems.
- Beyond the methodological aspects, we have shown that social factors have an impact on farming systems at least as strong as economic or agronomic factors. However, because such social factors are different according to the villages and the sites but related to environmental ones, they have different and non-linear effects on the village evolutions[16].
- Moreover, beyond the quantitative differentiations, the integration of these factors informs on the discriminations between categories of gender and of family groups. Such informations that cannot be approached with other methods may help to increase the proportion of people benefiting from development projects in Niger and for the whole Sahel.

The present simulations take in account two perceived main factors of social differentiation. In the future, additional factors that were observed in the field and may be important factors of emergence could be included. For instance, the transhumant Fulani herders, who had formerly an important role of fertility transfer are not simulated, as well as the high proportion of divorces (two marriages in five according to our observations) that reinforce the autonomy of women through their herds and their gardening productions. Additional social changes could be considered as the driving forces of evolution of farming systems: the progressive settlements of transhumants and nomads, the choice of activity according to the gains in terms of social reputation and economic gains, the development of communication network and in particular road and transportation networks that have allowed in the past the take-off of the seasonal migration activity. The introduction of a development project may also be an important trail from a more operational decision-support point of view.
More fundamentally, modeling social systems poses problems as underlined by Chattoe (2002): simulating individual behavior implies to postulate some reasoning, even if these are defined in the simplest possible way. Moreover, it requires parameterization of the factors that have an influence on these behaviors. Choosing such reasoning's and the related parameters are open to discussion unless based on systematic investigations still too heavy, too long-term and too costly to justify. It is difficult to establish the extent of such changes, the impacts and the "weight" of each parameter because this needs time for investigation but also because these phenomena take place over several generations.

5 References

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[16] In the village archetypes we considered, social constraints are more and more strong along a gradient equivalent to the environmental constraints' one. Therefore, our simulations show an overlapping of such constraints according to an equivalent gradient. Meanwhile, this contiguously growing constraints along the same gradient is acknowledged in the literature and is not an artifact in Nigerien Sahel. An extension of this work may be to analyze Sahelian site situations where social and environmental factors belong to different and even opposite gradients.

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6 Appendix

Table 3. 100 years evolution of selected indicators for the three sites in a No-Evolution Scenario (fixed unitary family & customary inheritance system) (Mean + standard deviation; n=20).

		Zermou					
		1	2-25	26-50	51-75	76-99	
Environ-mental sustainability	Arable land saturation (%)	29.9	79.6	94.3	100	100	A
	Pearl millet yields (quintals / ha)	5.4 ± 0.8	4.6 ± 0.7	3.8 ± 0.5	3.6 ± 0.5	3.6 ± 0.5	B
	Vegetation cover (% of the initial cover)*	80.5 ±15.8	39.7 ± 5.2	16.8 ± 4.8	10.5 ± 4.4	7.6 ± 1.7	C
Average population performances	Population size	47 ± 12	69± 24	152 ± 58	313 ± 120	495 ± 284	D
	Income per capita (in €)	18.3 ± 8.1	17.3 ± 0.4	5.7 ± 0.8	4.2 ± 1.0	3.3 ± 0.7	E
	Cropped surface per capita (in ha)	2.3± 0.6	4.2 ± 0.5	2.2 ± 0.2	1.2 ± 0.1	0.7 ± 0.1	F
	Livestock size per capita (in L.S.U. equiv.)	0.4 ± 0.1	0.5 ± 0.2	0.4 ± 0.2	0.6 ± 0.2	0.4 ± 0.2	G
Social sustainability	Male/female income ratio	1.6 ± 0.2	1.7 ± 0.2	1.7 ± 0.2	2.8 ± 0.4	4.3 ± 0.5	H
	Coefficient of Gini between families	0.48 ±0.14	0.55 ±0.11	0.60 ±0.08	0.65 ±0.08	0.68±0.09	I
		Fakara					
		1	2-25	26-50	51-75	76-99	
Environ-mental sustainability	Arable land saturation (%)	04.7	13.2	59.8	94.2	97.8	A
	Pearl millet yields (quintals / ha)	5.8 ± 0.9	4.8 ± 0.6	4.4 ± 0.3	4.1 ± 0.2	4.0 ± 0.2	B
	Vegetation cover (% of the initial cover)*	93.9 ± 7.2	81.5 ± 4.1	46.4 ± 5.3	18.3 ± 3.0	12.3 ± 2.3	C
Average population performances	Population size	50 ± 2	80 ± 15	223 ± 69	639 ± 209	1246 ± 386	D
	Income per capita (in €)	39.7 ± 5.1	30.9 ± 1.5	14.3 ± 1.1	12.4 ± 0.9	10.5 ± 1.2	E
	Cropped surface per capita (in ha)	0.5 ± 0.2	0.9 ± 0.3	1.4 ± 0.2	0.8 ± 0.1	0.4 ± 0.05	F
	Livestock size per capita (in L.S.U. equiv.)	0.4 ± 0.1	0.5 ± 0.2	0.4 ± 0.2	0.6 ± 0.2	0.8 ± 0.2	G
Social sustainability	Male/female income ratio	1.7 ± 0.2	1.4 ± 0.1	1.3 ± 0.1	1.9 ± 0.3	2.3 ± 0.4	H
	Coefficient of Gini between families	0.50 ±0.11	0.53 ±0.06	0.61 ±0.02	0.68 ±0.02	0.74 ±0.02	I
		Gabi					
		1	2-25	26-50	51-75	76-99	
Environ-mental sustainability	Arable land saturation (%)	04.3	07.1	24.3	67.1	98.4	A
	Pearl millet yields (quintals / ha)	9.3 ± 1.8	5.4 ± 0.7	4.9 ± 0.4	4.4 ± 0.3	4.2 ± 0.2	B
	Vegetation cover (% of the initial cover)*	105.2 ± 8.4	93.8 ± 4.5	63.2 ± 6.7	30.6 ± 4.9	14.9 ± 1.9	C
Average population performances	Population size	51 ± 1	75 ± 15	189 ± 53	579 ± 169	1591 ± 419	D
	Income per capita (in €)	43.8 ± 8.6	32.6 ± 4.3	17.0 ± 1.7	20.5 ± 2.2	36.3 ± 2.9	E
	Cropped surface per capita (in ha)	0.4 ± 0.2	0.5 ± 0.2	0.6 ± 0.1	0.5 ± 0.1	0.3 ± 0.08	F
	Livestock size per capita (in L.S.U. equiv.)	0.4 ± 0.1	0.6 ± 0.2	0.7 ± 0.2	0.8 ± 0.1	1.1 ± 0.3	G
Social sustainability	Male/female income ratio	2.1 ± 0.2	1.9 ± 0.1	1.6 ± 0.1	3.5 ± 0.2	5.7 ± 0.5	H
	Coefficient of Gini between families	0.53 ±0.14	0.61 ±0.09	0.59 ±0.03	0.63 ±0.01	0.66 ±0.02	I

* Combined weed and shrub vegetation

Table 4. 100 years evolution of selected indicators for the three sites in the Evolution scenario (family organizations & inheritance systems can change) (Mean + standard deviation; n=20)

		Zermou					
		1	2-25	26-50	51-75	76-99	
Environ-mental sustainability	Arable land saturation (%)	28.9	83.8	100	100	100	A
	Pearl millet yields (quintals / ha)	6.2 ± 0.5	4.9 ± 0.3	4.0 ± 0.2	3.9 ± 0.2	3.8 ± 0.1	B
	Vegetation cover (% of the initial cover)*	85.6 ±11.1	42.2 ± 4.1	18.2 ± 4.9	10.9 ± 4.0	8.0 ± 1.5	C
Average population performances	Population size	50 ± 3	76 ± 11	181 ± 35	333 ± 93	545 ± 168	D
	Income per capita (in €)	21.6 ± 7.7	13.4 ±2.6	4.3 ± 0.6	4.4 ± 0.4	4.9 ± 0.4	E
	Cropped surface per capita (in ha)	2.1 ± 0.4	4.0 ± 0.5	2.0 ± 0.2	1.1 ± 0.1	0.7 ± 0.04	F
	Livestock size per capita (in L.S.U. equiv.)	0.5 ± 0.1	0.5 ± 0.1	0.6± 0.2	1.1 ± 0.2	1.3 ± 0.4	G
Social sustainability	Male/female income ratio	1.8 ± 0.3	1.7 ± 0.1	1.7 ± 0.2	2.7 ± 0.3	3.4 ± 0.4	H
	Coefficient of Gini between families	0.51 ±0.14	0.60 ±0.10	0.64 ±0.05	0.73 ±0.02	0.71 ±0.02	I
		Fakara					
		1	2-25	26-50	51-75	76-99	
Environ-mental sustainability	Arable land saturation (%)	04.6	10.8	55.4	81.2	88.5	A
	Pearl millet yields (quintals / ha)	6.3 ± 1.1	4.7 ± 0.7	4.4 ± 0.4	4.2 ± 0.2	4.0 ± 0.2	B
	Vegetation cover (% of the initial cover)*	94.1 ± 6.4	82.5 ± 3.9	47.0 ± 4.8	20.7 ± 3.0	13.0 ± 2.3	C
Average population performances	Population size	51 ± 1	80 ± 13	198 ± 54	421 ± 159	704 ± 156	D
	Income per capita (in €)	51.8 ± 6.7	53.4 ±2.4	11.2 ± 0.6	11.3 ± 0.4	13.1 ± 0.3	E
	Cropped surface per capita (in ha)	0.5 ± 0.1	0.7 ± 0.2	1.5 ± 0.1	1.0 ± 0.1	0.7 ± 0.03	F
	Livestock size per capita (in L.S.U. equiv.)	0.5 ± 0.1	0.6 ± 0.2	0.4 ± 0.1	0.5 ± 0.1	0.8 ± 0.2	G
Social sustainability	Male/female income ratio	1.6 ± 0.1	1.3 ± 0.1	1.2 ± 0.1	1.6 ± 0.2	1.9 ± 0.3	H
	Coefficient of Gini between families	0.50 ±0.14	0.54 ±0.05	0.60 ±0.03	0.68 ±0.02	0.68 ±0.02	I
		Gabi					
		1	2-25	26-50	51-75	76-99	
Environ-mental sustainability	Arable land saturation (%)	22.5	76.0	100	100	100	A
	Pearl millet yields (quintals / ha)	10.3 ± 0.7	5.8 ± 0.3	4.6 ± 0.2	4.4 ± 0.2	4.4 ± 0.2	B
	Vegetation cover (% of the initial cover)*	100.8 ± 9.2	47.3 ± 3.7	14.8 ± 3.4	12.3 ± 2.7	11.5 ± 2.6	C
Average population performances	Population size	51 ± 1	77 ± 12	210 ± 44	607 ± 102	1475 ± 199	D
	Income per capita (in €)	38.9 ± 7.8	26.2 ± 1.6	14.9 ± 1.0	16.7 ± 1.2	19.5 ± 3.0	E
	Cropped surface per capita (in ha)	2.1 ± 0.6	4.7 ± 0.7	2.3 ± 0.4	0.8 ± 0.1	0.3 ± 0.06	F
	Livestock size per capita (in L.S.U. equiv.)	0.5 ± 0.1	1.0 ± 0.2	1.4 ± 0.3	2.0 ± 0.4	2.5 ± 0.6	G
Social sustainability	Male/female income ratio	2.1 ± 0.3	1.8 ± 0.1	1.6 ± 0.1	3.9 ± 0.3	6.2 ± 0.4	H
	Coefficient of Gini between families	0.54 ±0.13	0.52±0.05	0.62 ±0.04	0.70 ±0.02	0.70 ±0.02	I

* Combined weed and shrub vegetation