An Agent-Based Model for understanding the Multiple Uses of Land and Resources Around Drilling Sites in Sahel

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Abstract : In Sahel, land and resources are used, depending on the season, by various actors with interests that are sometimes difficult to reconcile. The competition for space and time for access to natural resources induces a set of processes, including overgrazing and conflicts over access to water. In such a complex agro-sylvopastoral context, acquiring and formalizing knowledge about the practices and rules that govern the system is essential to helping and accompanying rural populations towards the sustainable management of their environment. Among the new modeling tools coming from the field of Artificial Intelligence, Agent-Based Models (ABMs) are now widely used to tackle the issue of integrated natural resource management. The rise of ABMs is partially due to intelligibility, not only by scientists from various research fields, but also by the stakeholders. It thus becomes easier to build an understandable representation of the system as an "artificial world" and to perform simulations to collectively test and discuss various resource management scenarios. In this article, we present a description of an ABM which has designed to formalize interactions between the biophysics dynamic of natural resources and socio-economic factors driving the land-use dynamics around the drilling of Thieul in the "Réserve sylvo-pastorale" (sylvopasture) of Ferlo.

Keywords: *Sahel; Integrated Natural resource Management; Grazing; Agent-Based Modeling; Senegal*

1. INTRODUCTION

Concerning natural resource management in Sahel, several social science and natural science approaches (participative and community approaches, cooperation and negotiation frameworks, holistic and systemic approaches, integrated approaches, and others) conflict with, contradict and complement one another in the field to sort out the hypotheses and answer questions about the sustainability of production systems. (Boiral and al., 1985). At the heart of these methodological approaches, Multi-Agent Systems (MAS) can facilitate discussion, and even the integration of experts' hypotheses and multi-disciplinary research questions, as well as the consideration of the ways, customs and practices of rural populations for the management of shared space. Furthermore, in order to build a basis for appropriate methodological and theoretical dialogue, the objective here is to model the knowledge acquired on the multiple use of resources and space around the drilling in Thieul. This involves developing interdisciplinary thought on the viability of pastoralism under inadequate bioclimatic conditions in a particularly sensitive ethno-social, cultural, economic and political context. The MAS, at the heart of this approach, will serve as a catalyst for the re-formulation
of hypotheses and research questions in the social and natural sciences.

2. DESCRIPTION OF THE STUDY ZONE

With a surface area of 1,031.46 km^2, the pastoral unit of Thieul is located in the sylvopasture reserve of Ferlo, approximately sixty kilometers southeast of Dahra. This land, adjacent to the Doli ranch on the border of the peanut basin, is at the heart of agricultural expansion and its corollary: the reduction of rangelands and the disputes among geographically stable and animal herding populations (Weicker, 1993), (Diao A., 2000), (Diouf A., 2000). The population is very diversified, consisting of three major ethnic groups: the Peul, the Seereer and the Wolof.

Due to its location, this agro-sylvopastoral land is a morpho-pedological, climatic and socio-economic buffer zone, which is what makes it so diverse. The local climate is typical of Sahel, with a few Sudanese influences, as indicated by the immense herbaceous coverage in the rainy season. Water resources consist of the permanent waterholes (wells, drilling and drilling antennae), as well as ponds and valleys located around Thieul with intermittent pluvial run-off.

These specific bioclimatic characteristics continue to attract new populations of farmers, of which the number of camps increased 70% between 1980 and 2000, compared to only 30% between 1935 and 1980 (Diouf A, 2000). This migrant flow resulted in a 13% increase and extension of the farming zones between 1980-1999, manifested by an agricultural fragmentation of the landscapes and a reduction of the rangelands from the south to the north.

The first planning and management tools negotiated between the various actors were developed and tested around a pastoral unit (PU). This concept of a pastoral unit refers to the space and all of the resources that are the focus of a pastoral drilling site (Faye M., 2000). In order to better understand the interactions between space, resources and the actors, we have established the following two objectives: (i) to develop a MAS to test hypotheses and intervention or event scenarios in order to better refine the various aspects of a comprehensive, multidisciplinary approach for the management of space and shared resources; (ii) to develop methodological frameworks and approaches for cooperation and/or negotiation with the actors in order to improve the resource-related decision-making processes.

The final step is to create tools and frameworks for cooperation in order to integrate the needs of the populations as faithfully as possible into the development projects, to establish the effective management of natural resources.

3. Multi-Agent Modeling

Multi-agent modeling has brought an innovative view of modeling and simulation to environmental science by providing the opportunity to directly represent individuals, their behaviors and their interactions simultaneously (Ferber, 1995). Many authors use this approach (Bousquet, 2001), with a certain amount of success, to try to understand the interactions between social and ecological phenomena: (Barreteau, 98) in the irrigated areas in the valley of the Senegal River and (Bah, 1998) (Bah 2001) concerning pastoralism in the Sahel region.

3. 1 Model Description

In this section, we identify and describe all the entities of our model and their relations. For this, two interacting fields have been established: spatial and social.
Also, we have to notice that this model "Thieul Model" have been implemented with the Cormas[1] platform designed by CIRAD[2].

3.1.1 The Spatial Aspects

Access Area: The area of influence of the drilling which includes the pastoral unit of Thieul, consisting of elementary entities (pixels or patches). Its representation comes from the map created by the actors, prepared by the local population of the Thieul PU. Generally, the resolution of each elementary entity is brought to 300x300 meters (90,000 m²).
Field: This spatial entity is composed of the areas planted with peanuts or millet in the rainy season, farmed from July to October or November by the farmers and farmer-herders of Thieul.
Resources: This entity consists of all the natural resources used by the various users. They fall into the following categories:
Forage: The primary vegetal production available with the first rain and eaten by the animals throughout the year. Herders classify them into four functional units, according to topographical and morpho-pedological factors: (i) the pastures of *caanngol-baljol* (shallows and hydromorphic zones) are of very high quality; (ii) the pastures of *seeno* and *yongre-seeno* (sandy soil) are very good in the rainy season and acceptable to mediocre in the dry season; (iii) the pastures of *nyaargo – sangre* (surfacing of duricrust, clay-gravel) are very good and greatly sought after (*Zonia glochidiata*) at the end of the rainy season, beginning of the dry season, but their state is mediocre to worthless in the dry season; (iv) the pastures of *luggol* and *yongre-luggol* (clay-sand soil of the fossil valleys) are moderately good in the rainy season and acceptable to mediocre in the dry season.

Water: One of the key resources of the pastoral systems of Ferlo, essentially consisting of intermittent and permanent waterholes. The intermittent waterholes consist of the entire surface

[1]Common-pool Resources and Multi-agent Systems
[2]Centre de coopération International en Recherche Agronomique pour le Développement

hydrographic network (**pond**, **streams**, etc.) fed by precipitation in the rainy season. In this semiarid climate, deep water drilling and its antennae and converted ponds represent the only permanent waterholes (**main drilling, drilling antennae, wells,** etc.), used by the population and the livestock the entire year, and particularly in the dry season.
Forests: These are wildlife and forest reserves, reforestation zones, or natural parks.
Habitat: These are human residences or settlements and their spatial configurations. We have identified two types:
Permanent habitat: This is the case for a village that occupies a large amount of space. It is often the administrative center of the rural community and sometimes of the main drilling site. Its population consists of geographically stable residents (farmers, merchants, opinion leaders, government officials);
Seasonal habitat: This category has two sub-types: (i) the *seedaano* or dry season camp is located within the area of influence of a permanent waterhole (**main drilling site, drilling antennae, wells,** etc.) accessible to the population and livestock. It is the sporadic habitat of herders and farmer-herders in search of water and pastures in the dry season. (ii) the *ruumaano* rainy season camp is generally located in littoral zones in the sandy substrate of the *seeno* near intermittent waterholes (**pond**, **stream**). This is the preferred habitat of herders and farmer-herders in the rainy season and in the beginning of the dry season until the harvest of the fields.

3.1.2 The Social Aspects

Actor: A type of entity or social formation that directly or indirectly uses the natural resources of the Thieul pastoral unit.
Space user: An actor that directly uses a natural resource. We have identified three main categories:
Herder: He owns a herd of cattle and small ruminant animals that he leads where the seasons take them, between quality pastures and waterholes, from one camp to another. In response to the variability in space and time of the primary resources, the herders have adopted a strategy based on mobility. In Thieul, all herders are a part of the Peul ethnic group and account for 22% of the surveyed population.
Farmer-Herder: He has a herd of cattle and small ruminant animals and a plot of farmland that he farms in the rainy season near his *ruumaano*. He is less mobile than the herder and often entrusts his herd in transhumance to his eldest sons. Unlike the herders, this category of agents is more ethnically heterogeneous (*Peul, Seereer, Wolof*) and accounts for 78% of the surveyed population.
Farmer: He owns or rents one or more plot(s) of farmland on the seeno or the *caanngol-baljol* that he farms in the rainy season, sown with the first rainfall, *Ceetcelde, Duungu,* and harvested at the beginning of the dry season, *Kawle, Dabbuunde*. He grows mainly peanuts and millet. This category is most often composed of disciples of the Mouride brotherhood, predominantly consisting of *Wolof* and *Seereer*.

4. EXPERIMENTATION AND DISCUSSION

4.1 The Parameters of the Model

In the Thieul model, the main actors/space users (farmer, farmer-herder and herder) have been divided into three categories (large, medium and small) with their attributes (Table 1). The values of these attributes are adjusted according to rainfall (Table 2).

- Rainfall: This is a thirty-year record corresponding to a Normal Pluviometric (NP). Thus, depending on the annual rainfall, or rainfall (P), the latter can be qualified as good (GP >= 350 mm), average (200 mm <= AP < 350 mm) or low (LP < 200mn) with respect to the pluviometric average calculated over 30 years. A data entry interface defines the chronological series used for each simulation scenario.

Actors / Size	Herder	Farmer	Farmer-Herder
Large	70 UBT*	11 fields	70 UBT* and 11 fields
Medium	30 UBT*	9 fields	30 UBT* and 9 fields
Small	10 UBT*	1 field	10 UBT* and 1 field

Table 1: Typology of the Actors and their Attributes.

Actors / Rainfall	Herder	Farmer	Farmer-Herder
Good	+5 UBT*	+1 field	+ 5 UBT* et + 1 field
Average	+3 UBT*	+0 field	+3 UBT*
Low	-3 UBT*	-1 field	- 3 UBT* and – 1 field

Table 2: Variation of the Attributes with respect to Rainfall.

The carrying capacity of a pasture is the quantity of livestock that the pasture can support without being damaged. It is expressed in tropical livestock units (UBT) 1 UBT = 1 250-kg cow or four small ruminant animals.

We have established the minimum surface area of a field entity at one hectare, or 10,000 m². On the resource map for the model, the spatial resolution of the pixel or patch is 90,000 m², which means that one patch can contain 9 fields. Therefore, in order to calculate the theoretical carrying capacity (TCC), you multiply the sum of the pixels that compose each pasture by the number of UBTs supported in a good, average or low year. Based on this general theoretical carrying capacity, agrostological studies estimate that only half (50%) is potentially usable by the animals. The rest is lost to the treading of the animals or deterioration of the foraging value, or is destroyed by fire (Boudet G., 1984).

The model must next calculate, for all six unit types on the map, the resources that present, at the beginning of the simulation, the theoretical carrying capacity, with respect to annual rainfall (Table 3). It must also calculate the real carrying capacity (RCC), which is equal to the total number of farmer-herders, multiplied by the sum of their attributes in UBTs.

Unit Types	**Carrying Capacity in ha/UBT/yr**		
	Good	**Average**	**Low**
Caanngol-baljol	8	7	4
Gese	3	2	0
Luggol	9	8	5
Nyaargo-sangre	6.5	5.5	2.5
Seeno	7	6	3
Yongre-seeno	7	6	3

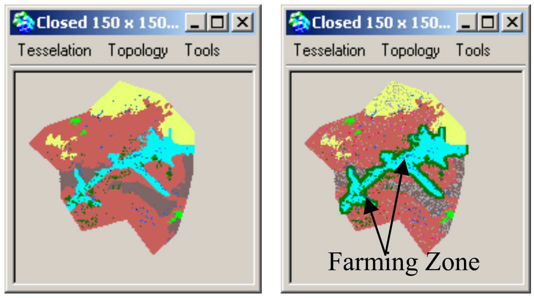
Table 3: Variation in the Carrying Capacity of the Pasture Types with respect to Rainfall.

4.2 The First Scenarios

In our tested simulations, we took into consideration the same number of space users, which was 30 farmers, 30 farmer-herders and 30 herders, with the same distribution in size for the three types of users: 10 large, 5 medium, 10 small.

● Rainfall: Good over 30 years

The objective was to verify the difference between the theoretical carrying capacity and the real carrying capacity as well as the evolution of the agricultural zones in order to verify the adequacy of the supply for the demand over 30 years (Map 2).



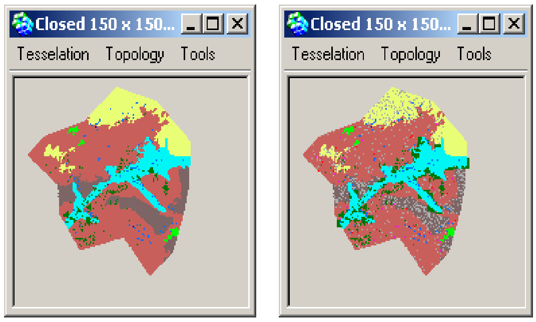
Beginning of the simulation 30 years later

Map 2: Good Rainfall

The cartographic results of this first scenario indicate an extension and aggregation of the farming zones (in green or dark gray) along the luggol (valley) thus dividing the pastoral unit into two zones, the north and the south. This saturation of the space by the farming contingent would likely cause coexistence problems between the pastoral and agricultural activities in the zone if passageways for the animals were not planned for in the pastoral development infrastructures.

● Alternating Rainfall: Good, Average, Low

For this second scenario, the goal was to display the effects of alternating rainfall over thirty years on the mutations of the agro-pastoral space (Map 3).



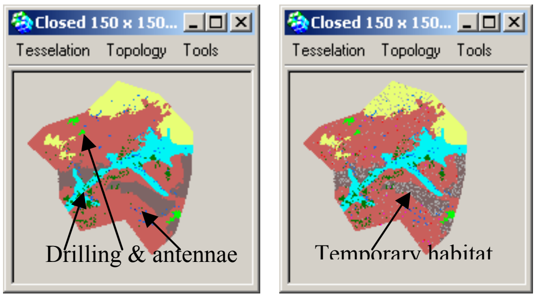
Beginning of the simulation 30 years later

Map 3: Alternating Rainfall: Good, Average and Low

The cartographic output (Map 3) reveals a fragmentation of the space by agricultural zones. The situation at the end of the simulation is similar to that of the current state of the agricultural dynamic observed by the diachronic analysis of the landscapes based on aerial photographs and satellite images from 1969, 1979 and 1999 (Touré and al., 2003).

● Rainfall: Average or Low Trend

The hypothesis for this scenario was to verify, under average to inadequate rainfall, the spatial configuration of the agricultural zones and the pressure on natural resources caused by animals. There resulted a decrease in the sown surface area as well as a decline in pastoral activity (Map 4).



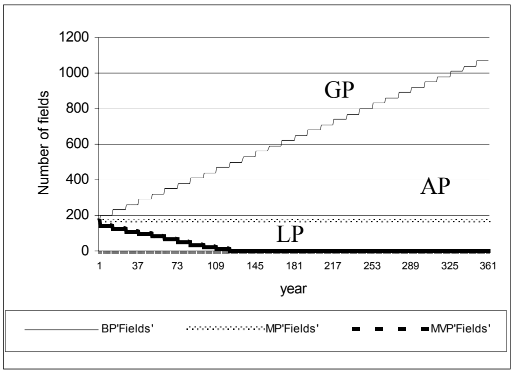
Beginning of the simulation *30 years later*

Map 4: Average to Low Rainfall

By comparing the three scenarios, we do note a decline in the temporary habitat (gray points) of the herders when the pluviometric trend is average to low. Their distribution follows that of the permanent waterholes, the main drilling site and its antennae.

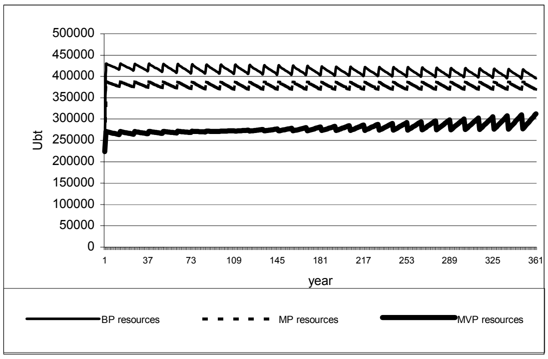
Likewise, the simulated scenarios over thirty consecutive years for good (GP), average (AP) and low (LP) rainfall reveal the following dynamics:

- For the fields, we note a linear increase over thirty consecutive good pluviometric years, stable in average years and decreasing in low years (Graph 1).



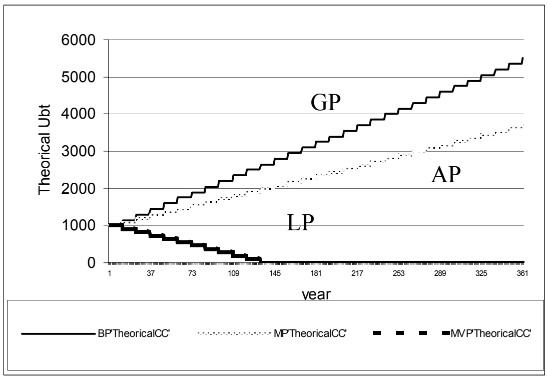
Graph 1: Evolution of the Fields.

- As for the resources, assuming the same human activities, their evolution and the initial parameters (Table 2), they would remain more or less in equilibrium with respect to their overall dynamic, regardless of the scenario in consideration (Graph 2). The increase in the same curve in low rainfall is due to the absence of animals beginning in the first 6 years, which promotes a "natural regeneration" of the basic resources.



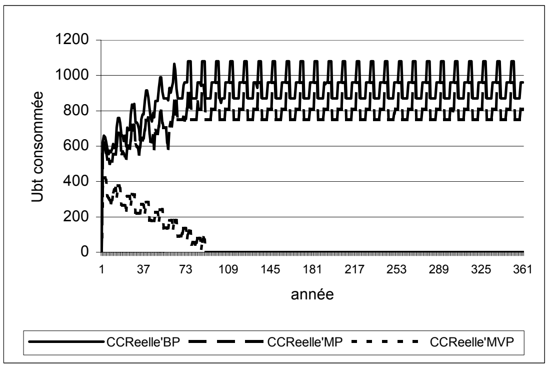
Graph 2: Evolution of the resources at the PU level.

- The evolution of the theoretical carrying capacities at the resource map level indicate an increase in good and average years, but a decline and even irreversible deterioration over thirty consecutive low years (Graph 3).



Graph 3: Evolution of the Theoretical Carrying Capacities.

However, the real carrying capacities corresponding to the potential resources consumed by animals in good and average years tend to evolve linearly in the same direction, unlike in low years (Graph 4).



Graph 4: Evolution of the Real Carrying Capacities.

Other scenarios can be tested by varying the number of actors or their categories, or by reusing the real inventory data at the Thieul pastoral unit level. The same is true for the rainfall recorded over the last thirty years in Thieul.

5. Conclusions and Outlook

These first simulations illustrate the effectiveness of the MAS in understanding the interactions and dynamics of complex systems. In creating the Thieul model, from the outset, we preferred to review all knowledge from scratch as well as to share spatial and temporal representations of the resources between the various actors and researchers.

The first results allow us to foresee the possibilities that the MAS offers in testing hypotheses and intervention or event scenarios for the management of shared space and resources. The experiment promoted the emergence of a shared, shareable representation as well as improved, mutual understanding among experts and actors.
The development of such a tool is all the more important because it is a decisive step in the creation of a common and even concomitant approach, to agro-ecological systems and socio-economic systems for the sustainable management of space and resources.

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