Web appendix to "Simulating the Impacts of Climate Variability and Change on Crop Varietal Diversity in Mali (West-Africa) Using Agent-Based Modeling Approach", by Mahamadou Belem , Didier Bazile and Harouna Coulibaly, published on 31 March 2018 in *JASSS-Journal of Artificial Societies and Social Simulation*, 21(2) 8: http://jasss.soc.surrey.ac.uk/21/2/8.html [DOI: 10.18564/jasss.3690]

This document provides a detailed description of the modelling process, data collection and the ODD description of the SIMAS model.

Modelling process

Step 1: System delimitation and identification

The objective was to allow the different stakeholders involved in the modelling process to reach a common understanding of the problem to be resolved and a shared representation of the system, and to define the scope of the study. More than ten participants (researchers, farmers, governmental organisation, non-governmental organisation) took part in this one-day session. In addition, a facilitator and a modeller managed the different modelling process.

Specifically, this step concerned the description of the system using an overview diagram (Figure 1) after presenting an example. The description of the system at this step consisted of identifying in the following order: 1) the main functions (or processes), 2) the actors and resources, and 3) the communication systems through which the actors interact and exchange resources (Figure 1).

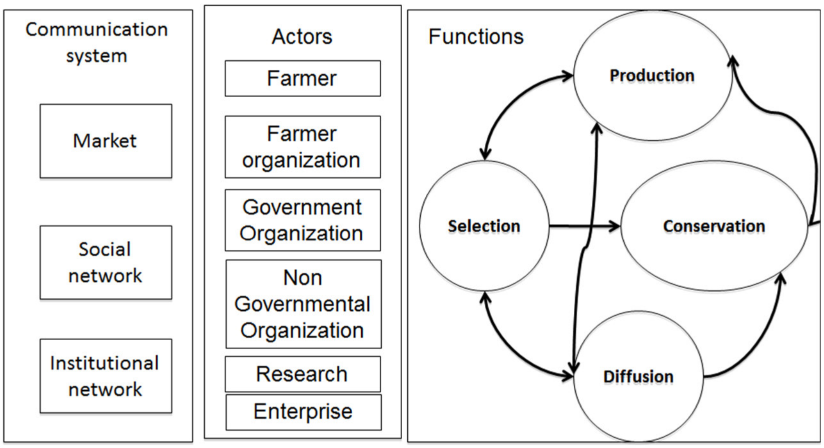

Figure 1: The overview diagram of the model

The identification of the main functions involves the decomposition of the system into several sub-systems considering the stakeholders point of view.

The communication system describes the different networks through which the actors interact, exchange seeds, and information about crop varieties. During this first workshop, the participants provided the description orally and the modeller translated it into the overview diagram.

An overview conceptual model on agrobiodiversity management in Mali was developed. The resulting conceptual model is based on four main functions, six actors and three communication systems (Figure 3). The first function is "agricultural production", which concerns grain and own seed reproduction. The second is "conservation", including in-situ and ex-situ conservation. The in-situ conservation driven by farmers provides the resources for maintaining seed reproduction at farm level. The ex-situ conservation driven by researchers and enterprises enables the conservation of genetic resources for various uses for example to analyse seeds traits, to characterize genotypic and phenotypic expression of varieties and to create new crop varieties through breeding programs. The third function is "seed selection", through which researchers and farmers create and improve crop varieties. The fourth function is "diffusion", describing the exchange of seeds and information about varieties among different actors.

From the participants description, we built a typology of actors: Farmer, Non-Governmental Organization (NGO), Research, Enterprise, Government Organization (GO) and Farmer Organization (FO).

After, we identified the communication systems that are composed of the market, the social network and institutional network on which seed access depends. The social network defines the social relationships between farmers and constitutes the support of the usually called "informal seed system" even if all the social relations are codified in a traditional community and the social network could also include strong relationships with farmers organization with delimited status and norms. The institutional network describes links and interactions between the different institutions for seed access, seed distribution and seed improvement: FO, NGO, GO, Enterprise, Research. In other words, the institutional network describes the formal seed system defined to create and to register new varieties and after to diffuse them. Market defines the institutional context in which seed and grain buying and purchasing take place.

Step 2: Description of actors and resources

Step 2 also was conducted collectively guided by one facilitator and one modeller. The objective was to identify and describe each participant's point of view on each actor in the target system in order to provide a multi-point of view description of the actors and the resources.

In this step, the description was driven by an actor diagram (Figure 2). An actor diagram describes the roles and interactions that an actor handles in different functions and communication systems. As in the previous step, participants provided the description orally and the modeller translated their description into the actor diagrams.

The description consists of identifying first the roles of the different actors in different functions; in other words, what each actor does in the different functions. A role correspond to a point that the participants have on the actor. For example, Actor "Farmer" drives many activities in different functions. Farmer cultivates, selects, maintains and sells or exchanges seeds in the functions "Production", "Selection", "Conservation" and "Diffusion" respectively (Figure 2).

Second, the participants identified the interactions in which the actors are involved in the communication system, the resources exchanged and the actors with which he interacts (Figure 2).

After identifying and describing the actors, the participants identified and described the main resources. The main resource in this study was crop varieties, considered as seed lots by farmers in the management of their agrobiodiversity. By abstraction and generalization, we defined the concepts of Specie and Variety to describe the diversity of crop varieties by species. The concept of Specie designs a group of Varieties of a same crop species. To describe a variety, the following characteristics were selected by the stakeholders: the name of the variety, the properties related to the physical aspects (colour, size, etc.), properties related to production (cycle of production and yields under different climate and environment configurations), properties related to grain use (taste quality, transformation of grains and quality of grains) and properties related to economic aspects (purchase and sale prices of grains and seeds). These properties were retained because farmers' decisions regarding the production and use of the varieties depend on them.

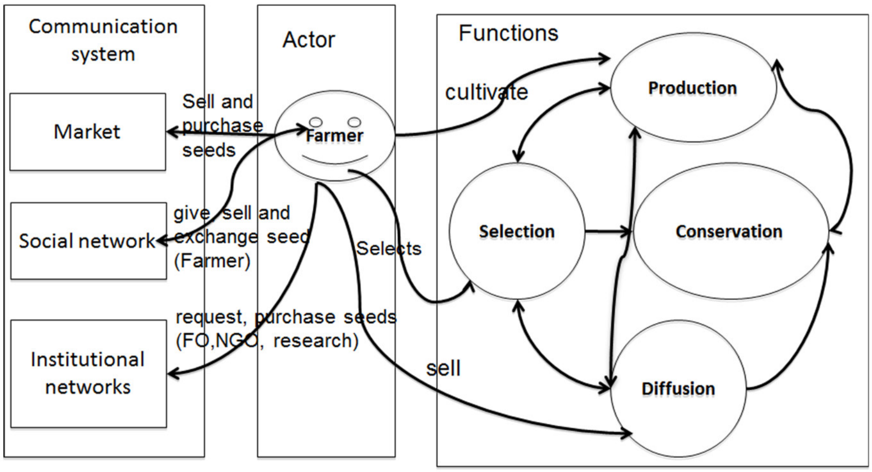

Figure 2: An actor diagram: description of the actor Farmer in the seed system

Step 3: Description of the conceptual model

The first description of the conceptual model was developed with researchers. A formal conceptual model then was defined on the third day of the workshop by the modeller based on the participants' descriptions and using Unified Modelling Language (UML). The formal conceptual modelling at this step is done through the transformation of the overview diagram, the actor diagrams and the resources description. The functions then are transformed to sub-models, the communication system to social networks, each type of actor to agents and resources to objects from agent-based point of view. Their acquaintances are defined thank to their relationships in the communication system. The actors' roles in different functions are transformed to behaviour and described using the activities diagram. Based on the actor diagrams, the interactions between agents are identified and described using sequences diagrams.

To complete the description of the conceptual model, we also used results of a range of studies about crop varietal diversity management modelling (Abrami et al, 2008; Bazile & Abrami, 2008; Bazile et al, 2012c; Rousseau et al, 2012) and surveys in Mali (Bazile & Soumaré, 2004; Coulibaly et al, 2008; Alfonso, 2010). The results of these studies also were used to define in part the parameters of the model.

The conceptual model was then presented and validated by the participants.

Step 4: Definition of the scenarios and identification of indicators

The stakeholders developed a set of scenarios for the introduction of improved varieties in production system in Mali. The objective was to assess the dynamics of agrobiodiversity in presence and absence of policy interventions in the context of climate change.

Two main questions have been asked to the participants: how a new variety can be introduced in a production system? What are the barriers and constraints to the large adoption of improved varieties?

Participants identified two schemas of varieties introduction. In the first schema, the introduction of a new variety is initiated by the farmers themselves. In the second schema, it is supported by GO, NGO and other organizations through different interventions.
According to the participants, the strategies for varieties introduction should take into account major barriers and constraints to adoption of new varieties that are fertilizers and labour access, land access, market access, access to information, the poverty, climate variability and change, soil, institutional context.
Based on the two schema and identified barriers and constraints, two policy for improved varieties introduction were identified with the participants: general agricultural intervention and variety-specific intervention. The two policy interventions both give inputs (seed, fertilizers) or other supports (equipment, cash) to farmers to increase their production. With the general agricultural intervention, farmer beneficiaries are not constrained to cultivate the specific improved varieties, while the special variety-oriented intervention benefits only farmers cultivating improved variety.
Based on the two policy interventions and climate variability and change impacts, four scenarios were identified (Table 1). The first scenarios aims to assess the adoption of improved variety in absence of policy intervention. The second one aims to assess the adoption of improved variety in presence of general agricultural intervention. The third scenario aims to assess the impacts of special variety-oriented intervention. Finally, the last one is related to the impacts climate change and variability on agrobiodiversity. Six indicators were identified to assess the agrobiodiversity dynamics at different scales under different scenarios (Table 2).
After, modellers compared the selected scenarios with the analysis from literature on agrobiodiverstiy management and varieties introduction in order to have an international scientific confidence on these results (Almekinders, 2001; Almekinders et al., 1994; Bellon, 2001, 2004; Bellon, 2006).

Table 1: The description of the scenarios selected in the modelling process

Scenarios	Description	Research questions
Scenario 1: Varieties Introduction	It is based on the actual situation and the introduction of new varieties.	What would be the crop varietal diversity if any intervention is proposed?
Scenario 2: Agricultural intervention	It aims to improve production, seed access, farmer income by proposing equipment, fertilizers and cash to farmers.	What would be the impact of agricultural intervention on the development and conservation of crop varietal diversity?
Scenario 3: Varieties vulgarization	It aims to support the adoption of new varieties by proposing aids to farmers (cash, fertilizers, facilities) if they cultivate the supported varieties.	How would the vulgarization of a limited number of varieties impact crop varietal diversity?
Scenario 4: Climate change	It aims to analyze the impacts of climate on the dynamics of crop varietal management by the farmers	What would be the impact of climate change on crop varietal diversity?

Table 2: The indicators for the analysis of the scenarios

Type of output	Description	level
Production	The annual production for each variety (ton)	Plot, farm, village
Adoption	The number of persons that cultivate a variety	Farm, village
Diversity	The number of varieties per species	Farm, village
Spatial diversity	The spatial distribution of varieties	Farm, village
Varieties distribution	The number of varieties per species per farmer	Farm, village
Rainfall	The annual rainfall (mm)	Village
Season duration	(days)	Village
Cash	The cash production per farmer	Farm, village

Step 5: Implementation of the model

A generic agent-based model is implemented using the Mimosa platform (Müller, 2004) based on the conceptual model , the scenarios and indicators, which are defined with the stakeholders. The model integrates an experimental framework that allows the model structure to be separated from the context of use. This increases the genericity and the usability of the model. The input data defines a typology of farmers, their social and institutional networks, the climate, policy interventions, the description of a range of varieties (their characteristics and yields according to the soil type and climate) and scenarios to simulate. A *Postgres* database is associated with the model to store input data and output.

After the model implementation, a one day workshop is organised to present the model to the participants and to discuss the structure of the model, input and output data, and the primary results.

Step 6: Validation of the model using role playing games

Researchers from different disciplines and local stakeholders developed a consensus on the representation of agents, resources and dynamics of the system. The specific objective was to validate the structure and the dynamics of the model: objects, spatial and temporal scales, actors and their decision making, and the system dynamics. In order to acquire confidence in the model, and because real confidence is based on experts' and farmers' points of view, RPGs and discussions included farmers, specific resource persons, representative of different geographical regions, with extensive knowledge on varietal dynamics. The organization of the RPGs was adapted to the structure of the model: we introduced the types of actors, resources and communication systems contained in the model.

In total, ten persons took part in the RPG: six representing three farmers and their assistants; one, a Farmers Organisation: one, the market, and two facilitators.

The three "farmers" came from three different villages and each represented a small, medium and large farmer (according to the cultivated area of the farm). The large farmer played the role of innovator, the medium farmer the role of imitator, and the small farmer the role of conservator. The players' strategies corresponded to those defined in the model, but may be adapted during the game if they do not correspond to the reality of the farmers' practices or the management of the cropping systems of the farmers' agroecological zone.

Each farmer player represented a farm characterised by a number of people to nourish, i.e. his family. Initially, each farmer had a set of resources: a farm, a set of equipments, a seed stock of different varieties, grain, and cash. The farmers cultivated a range of varieties of one or several crop species, planning and executing their activities through an Excel file, the farmers' "dashboard", which described the current resources, the plan of production, the farmers' allocation of land, the harvest and the use (consumption, selling and storage) of the harvest. The descriptions of the varieties were provided on a blackboard to allow players to follow their yields in the different climate configurations.

Five years were simulated during the RPG, which simulated the introduction of two improved sorghum varieties by the Farmer Organisation, and assessed the impacts of climate variability and policy interventions on crop varietal diversity. Each year, corresponding to a particular climate configuration (beginning, duration and the precipitation level) and a specific policy intervention (distribution of equipment, cash, varieties, etc.), was scheduled first to valid the structure and then to explore the climate and policy impacts.

According to the policy scenario, the Farmer Organisation offers support (equipment, fertilizers, cash, and seeds) to farmers at the beginning of each year. The facilitator then announces the beginning of the rainy season. Farmers drive their activities as defined in the conceptual model: definition of need in seeds, definition of land allocation, cultivation and production management, seed selection and seeking.

The results of the RPGs allowed us to understand farmers' strategies of that were not well defined in the model:

- Farmers determine their need for food according to the species and define the land allocation of varieties according to their criteria and need of food;
- Farmers determine the share of each variety in consumption according to their criteria, need of food and production;
- Farmers increase and decrease the number of varieties both according to the climate context but also to the size of his farm.

- Farmers do not adopt systematically and automatically a new variety. They test it for a
- few years before adopting it.

The model was improved by accounting for these observations, the new version presented to researchers for discussion.

Data collection

This study was achieved in the context of a pluridisciplinary research project, in which modelling supported the integration of the various knowledge of a range of local stakeholders as well as the researchers involved in the project. The simulations in this paper integrated data, including the cultivated varieties and their characteristics, farmers' socio-economic characteristics and climate (Table 3).

Table 3: Sources of data used for the simulation

Type of data	Sources of data	Specific attributes considered
Characteristics of varieties	(Bazile and Soumaré, 2004)	Diversity of soils linked to varietal diversity
	(Coulibaly, 2011)	Diversity of Sorhum in Mali and ditribution of the exchanges through specific seed systems
	(Kouressy, 2002)	Genetic Diversity and Photoperiodism of Sorhum.
	(Kouressy et al, 2003)	Genetic erosion of sorghum and diseapparition of specific varieties.
	(Vaksmann et al, 2008)	Photoperiodim of sorghum and relation with the end of the rainy season.
Typology of farmers	(Abrami et al., 2008)	Spatial analysis at different scales of seed exchanges
	(Bazile and Abrami, 2008)	Farmers' strategies to manage sorghum varietal diversity.
	(Bazile et al, 2003)	Farmers' spatial distribution and soil diversity.
	(Bazile et al, 2008)	Farmers' networks and Diversity of seed systems.
	(Coulibaly, 2011)	Individual and collective rules to manage sorghum diversity
Climate data	(Abrami et al., 2008)	Farmers' representation on the rainy season and associated practices
	(Kouressy, 2002)	Diversity of Sorghum cycles considering climate variations on a North South gradient in Mali
	(Kouressy et al., 2008)	Relation between sorghum cycles and climate data through photoperiodic coefficient.

(Vaksmann et al, 1996)	Assessment and Modelling of the end of the rainy season considering dataset on the beginning of the rainy season

Demography

Three farmers types characterize the simulated population: small, medium and large farmers (Table 4). The three types of farmers correspond to the current typology of farmers defined by the survey analysis (Bazile et al., 2003; Bazile and Soumaré, 2004; Abrami et al., 2008; Bazile and Abrami, 2008; Bazile et al., 2008; Alfonso, 2010; Coulibaly, 2011). The typology of farmers was defined considering varietal diversity management, importance of cropping system, and the main factors of production. The three groups -- small, medium and large farmers -- can also be described with three types of innovativeness behaviour: conservator, imitator and innovator.

Characteristics of varieties

The simulations took account five varieties of Sorghum kalosabani, Seguetana, Tiemarifing, Wassa and Grinka. Kalasabani, Seguetana and Tiemarifing are three local varieties while Wassa and Grinka are two improved varieties (Table 5). The characteristics of the varieties were described through a participatory approach to understand which traits interest farmers and from literature (Kouressy, 2002; Kouressy et al. 2003; Bazile and Soumaré, 2004; Vaksmann et al., 2008; Coulibaly, 2011). The main characteristics to which farmers pay a particular attention include soil adaptation, precocity and length of cycle of production, photoperiod sensitivity, pest and diseases resistances, yield, above ground biomass availability and quality for animal feeding, plant length as harvesting constraints, post-harvesting transformation, and culinary aspects. Yields of the different varieties were defined from previous studies, discussed with agronomist experts, and validated with farmers during Role Playing Games (Abrami et al, 2008).

The climate data

The climate data concerned principally the average length of the rainy season and the amount of the precipitation. In addition, based on the local stakeholders and experts (Vaksmann, 1996; Kouressy, 2002; Abrami et al., 2008; Kouressy et al., 2008) point of view, we defined the beginning, the length of the rainy season in the early, medium and late rainy season.

Table 4: Farmers’ typology in the simulations.

Type of farmers	Number of farmers	Farm size (ha)	Family size	Criteria	Level of equipment	Distribution of Innovation behaviours			Initial crop allocation	
						innovator	imitator	conservator	Variety	Land allocation (ha)
Small farmer (T1)	11	12	12	yield	1	4	4	3	Maize	4
									Kalosabani	2
									Seguetana	2
Medium farmer (T2)	12	20	28	yield	2	3	6	3	Maize	7
									Kalosabani	3
									Seguetana	3
Large farmer (T3)	14	30	43	yield	3	5	6	3	Maize	8
									Kalosabani	2
									Tiemarifing	3
									Seguetana	3

Table 5: Characteristics of the sorghum varieties from the farmers' perspectives.
(1) "Cycle of production" specifies the length of the production cycle; (2) "Taste" describes the taste quality of the grain; (3) "Seed conservation" specifies the amount of time (years) seed can be stored; (4) "Productivity" specifies the yield; (5) "Grain quality" describes the physical aspect of the grain; (6) " Resistance to drought" specifies the variety's capacity to resist drought; (7) "Transformation" specifies whether the variety's grains can be easily made into other products such as bread, cake, beer .

Varieties of sorghum	Cycle of production	Taste	Seed conservation (years)	Productivity	Grain quality	Resistance to drought	Transformation
	1 = short 2 = medium 3 = long	1 = bad 2 = medium 3 = good	1 = 1 year 2 = years 3 = 3 or more than 3 years	1 = bad 2 = medium 3 = good	1 = bad 2 = medium 3 = good	1 = bad 2 = medium 3 = good	1 = bad 2 = medium 3 = good
Kalosabani	1	3	3	1	1	3	3
Seguetana	2	2	2	2	1	1	2
Tiemarifing	3	3	2	2	3	2	1
Wassa	1	2	2	3	2	1	2
Grinkan	2	1	3	3	1	1	2

ODD description of the SIMAS model

Purpose
The model is developed to provide decision support tool to assess the impacts of climate change and variability and policies on crop varietal diversity at village territory level. The model provides a decision support tool to assess how the policy support could contribute to the adoption of modern varieties in the context of climate variability and change.

Entities, state variables, and scales
The structure of the model (Figure 3) is based on two types of agents - *Organization* and *Farmer* – and different types of objects representing the agents' knowledge, farmers' preferences, crop species and varieties, and agricultural interventions.

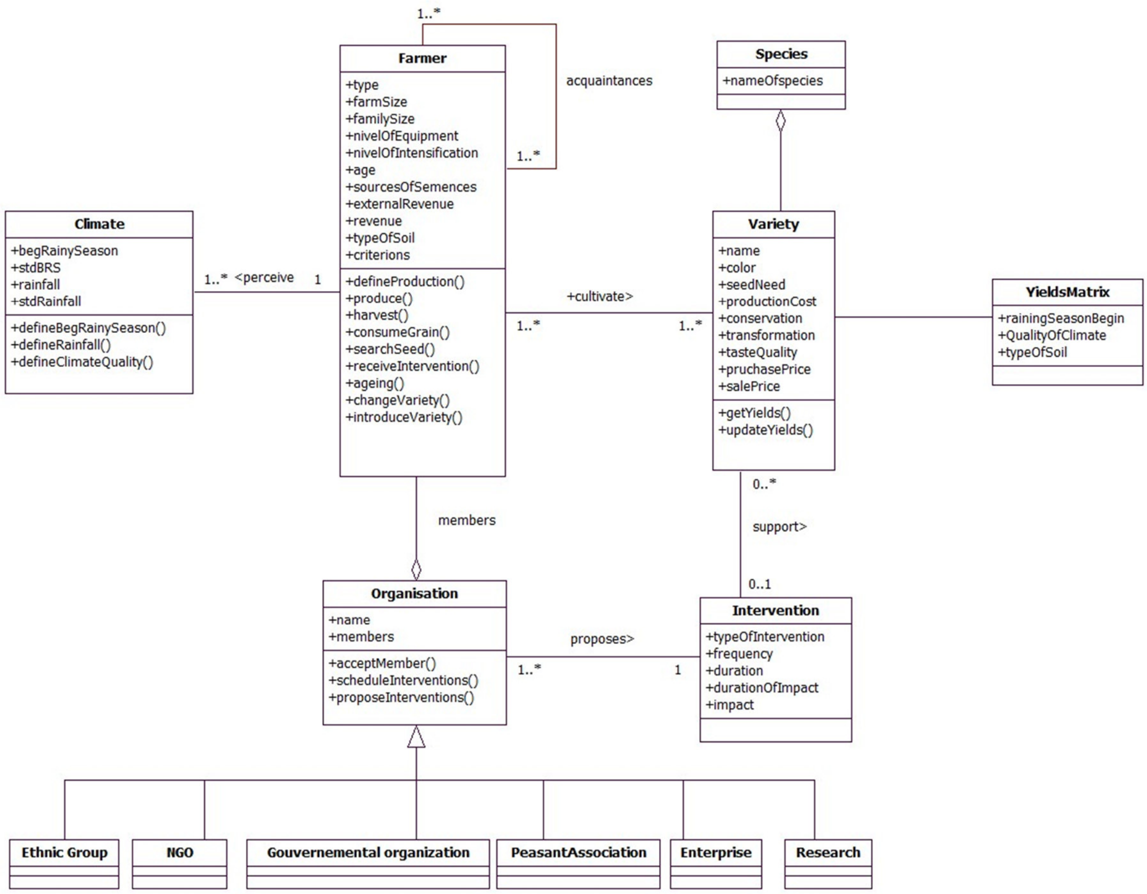

Figure 3: The UML class diagram of the model structure

Organization
An organization is both an agent and a group of farmers interacting to pursue the same goals. Organization can represent an Government Organisation (GO), Non-Government Organization (NGO), a Village, a Research, an Enterprise or a Farmer Organization (FO). In SIMAS , the role of an Organization is to support farmers and to promote varieties (landraces, High Yield Varieties "HYV", or other improved varieties) through different forms of interventions. An intervention is characterized by a weight, represented by a number comprised between 0 and 1; the duration of the intervention, the number of years intervention support continues; the frequency (years), determines the step of interventions proposition; and

the duration (years) of impact, or the number of years that an intervention affects a farmer. Four types of interventions are represented in the model:

1. *Intensification*: farmers are given fertilizer to improve and increase production, and the weight given to the intervention is positive.
2. *Equipment*: providing farmers with equipment increases the farmer to a higher level, and again the weight is positive.
3. *Seed accessibility*: farmers receive seeds, or cash to purchase seeds, which reduces the cost of seed access by value of the weight of the intervention, in this case negative..
4. *Income*: a farmer receive grants, which increases their income, a positive weight.

An Organization supports only its members. An intervention may be associated with a specific variety in order to support its adoption and diffusion, in which case, only farmers who cultivate the variety will benefit from the intervention. When an intervention is related to a variety, farmers reject the intervention if the characteristics of supported variety do not match their criteria. If an intervention is not related to a variety, farmers accept the interventions.

Farmer

The Farmer is the main agent of the model. Farmers' type determines their characteristics. A Farmer is a social individual interacting with other Farmers through a socio-professional network that determining seed access. Farmer can belong simultaneously to several socio-professional networks and interact only with the farmers of the same socio-professional networks.

A Farmer cultivates a range of varieties of one or several species of crop in order to deal with various concerns: consumption, seeds, and environmental/climatic constraints. Seed selection and grain production of cultivated varieties depends on the farmer's criteria. As varieties' characteristics are dynamic – they evolve over time – the Farmer's opinions of varieties are also dynamic, resulting Farmer changing varieties from time to time. Farmer changes varieties depending on his innovativeness strategy (cf. section 0), his relationships, the climate configuration, and other biotic or abiotic constraints.

Objects of the model

Species and Variety

The model takes into account a range of crop species. Each species is characterized by a set of varieties. A variety contains attributes describing its intrinsic characteristics. Soil adaptation, precocity and cycle length, photoperiod sensitivity, pest and diseases resistances, yield production, above ground biomass availability and quality for animal feeding, plant length as harvesting constraints, post-harvesting transformation, culinary aspects were the main characteristics in which farmers pay a particular attention.

Climate

The climate is characterized in the model by (1) the beginning and end of the rainy season, and the standard deviation of the beginning and (2) the minimum, average, and maximum annual precipitation, and the standard deviation of the average precipitation.

Other information related to climate concerns the beginning of the rainy season in the short, medium or long rainy season and the precipitation levels in the bad, medium and good season.

Process overview and scheduling

At the beginning of the simulation, the model initializes the different parameters and creates specific scenarios. Subsequently, simulations of different scenarios are scheduled. For each simulation, the population of farmers is first created and initialized, and then the climate is initialized. The model is based on monthly and annual time steps. Farmers schedule and execute their activities according to the various periods (months) of the year. Each month, the

Farmers' household uses a defined part of their stored grains for consumption, the amount depending upon the size of the family. If the stored quantity is insufficient for the family's food security, Farmer buys from the market to make up the deficiency.
At the first month of each year, the model computes the beginning of the rainy season, and informs Agents when the rainy season begins.
Farmers predict the end of the rainy season by determining the mean lengths of the last five years' rainy seasons, and then predict the yields of their varieties by defining the mean yields of each variety over the last five years. Based on the predicted end of the rainy season, Farmers define their plan of production, define their need in seeds, select varieties, seeks seeds in their socio-professional networks, and cultivates varieties. According to their innovativeness behaviour, Farmers decide whether or not to experiment with new plant material by introducing a new variety.
The model computes the precipitation level and the actual end of the rainy season informs Farmers of the end of the rainy season, and Farmers harvest their production. The model computes the yields of the different varieties based on the length of the rainy season and precipitation level. According to the computed yields and the amount of cultivated area (hectare) for each varieties, Farmers compute the total production of each variety , and then divides the yield for different uses (consumption, seed, and sale). To improve productivity by hectare, Farmers purchase equipment using a part of the income generated from the sale of their surplus production. Farmers can then decide whether or not to replace lower yielding varieties with higher yielding varieties. In addition, according to their level of equipment, Farmers can decide to increase or to reduce the size of cultivated area, and to introduce or remove varieties.
Organizations support Farmers through different interventions: seed, fertilizers, equipment, cash. These various interventions aim to improve farmers' income, food security, seed quality, and access to labour and market, as well as to favour introduction of new improved varieties.

Details

Input data
The model integrates a range of parameters (see Appendix) divided in two groups, the first of which allow defining the target site, i.e. the context to simulate. This context is described through its different attributes:

social: typology of farmers, socio-professional networks, diversity management, etc.,
economic, biophysical: varieties, yields, climate, soil, and
policy: policy interventions to support diversity management.

The second parameter group allows defining the simulation experimentations, i.e. the groups of scenarios to simulate. Each scenario is related to a climate scenario and a policy intervention.

Submodels
The model dynamics are based on climate dynamics, crop production and crop varietal diversity management by farmers and organizations' interventions.

The climate module
The climate dynamics are based on the determination of the beginning of the rainy season and the precipitation. The beginning and the end of the rainy season are computed randomly as follows:
beg = avrBegin + random(std,std)

Where the *beg* is the month that the current rainy season begins; *avrBegin*, the average start of the rainy season; and *std,* the standard deviation.

end = avrEnd + random(-std, std)

Where the *end* is the month that the current rainy season finishes; *avrEnd*, the average end of the rainy season; and *std,* the standard deviation.

Precipitation is determined as follows:

precipitation = avrPrecipitation + random(-std,std)

Where the *precipitation* (mm) is the current rainy season's precipitation ; *avrPrecipitation*, the average precipitation (mm); and *std,* the standard deviation.

Knowing the precipitation of the current rainy season, the precipitation level (the quality of the current rainfall), is defined based on the precipitation in bad, medium and good seasons.

Farmer decision module

The Farmer's main activity is to produce crops. To achieve multiple objectives, as well as addressing environmental variability, Farmers interact in their socio-professional networks to seek seeds, share and get information about varieties, and manage crop varietal diversity using different innovation strategies.

Seed seeking

In the Simas model, all Farmers and organizations are seed providers, creating several seed sources for farmers (other farmers,GO, NGO, market, Research, etc.) which depend on socio-professional networks. In addition, a Farmer has preferences regarding seed sources. A needy Farmer seeks seeds by starting with the most preferred source and so on until the satisfaction of his need. Suppliers (Farmers, Organizations) supply seed for free according to the available seed in stock after satisfying their own cultivation needs). If needy Farmer does not manage to meet his needs from usual sources, he seeks new suppliers from his socio-professional network. A Needy Farmer can also buy the seed from the market.

Varietal choice

When a Farmer needs to replace an existing variety or introduce a new variety, Farmer seeks information about varieties cultivated by other farmers or from the socio-professional networks in order to choose the most suitable. Varietal choice depends on farmer's criteria, with farmer's choosing, instead of optimal varieties, varieties which match his preferences and constraints.

First, agent Farmer evaluates the varieties according to his selection criteria and perceptions of attributes by starting with the most important criteria (Table 6). At each step, Farmer eliminates the least appropriate variety, and so on. The process ends when there is a unique solution, unless more than one solution remains at the end of the process, when farmer randomly chooses one variety.

Table 6: Example of process for variety selection according to farmers' criterion

Criteria	Variety 1	Variety 2	Variety 3	Variety 4	Selection
Yield (t ha^{-1})	5	3	~~2~~	6	V1, V2 and V4
Transformability	0.95	~~0.23~~	~~0.85~~	0.75	V1 and V4
Taste	1	~~0.50~~	~~0.60~~	~~1~~	V1

Innovativeness

A varietal introduction is defined as a technological innovation whose adoption and diffusion depend on the dynamics of social networks, the agents' criteria, and socio-economic contexts.

In Simas model, agents use different strategies for varietal adoption. We distinguish three types of farmers according to the strategies they use (Abrami et al., 2008): *innovator*, *imitator* and *traditionalist*.

The innovator agent

The innovator agent plays the role of seed introduction, seeking information about new varieties from socio-professional networks (farmer organisation, NGO, etc.). When an organization proposes new varieties, the innovator agent (1) determines from the cultivated varieties the least productive (with fewer yields) and (2) chooses from the new varieties the best variety using the strategy of choice. The innovator agent experiments the selected new variety in order to evaluate its performance through a comparison with the one the agent aims to replace. If the experiment is successful, innovator agent adopts the variety; otherwise he rejects it (Figure 4).

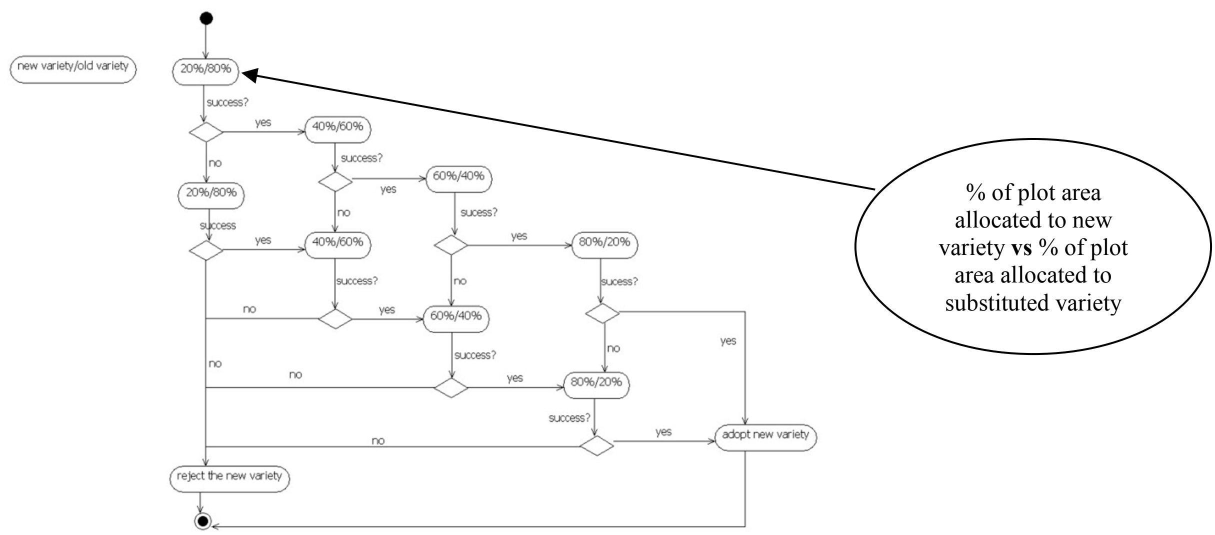

Figure 4: An example of a farmer decision process for a five-year variety experiment.

In the first year, 20% of the plot area allocated to the substituted variety is re-allocated to the new variety. Each year, if the yield of new variety is greater than the yield of the potential substituted variety, its cultivated area increases by 20%. If, however, during the experimentation process there are two failures — i.e., the yield of the new variety is less than that of the potential substituted variety — the new variety is rejected. Otherwise, after five years the new variety is adopted and the old abandoned.

The imitator agent

Each year, imitator agent determines the lowest yielding variety among the cultivated varieties, then collects information about new varieties produced by neighbours. According to his criteria, imitator agent chooses the most efficient variety in his immediate neighbourhoods. Unlike the innovator, the imitator does not experiment, but instead adopts (cultivates) a variety that has been already tested by innovators.

The traditionalist agent (conservator)
Traditionalist agent is conservative, changing his varieties only if they fail to renew seed stock and unable to find the same variety in his socio-professional networks. When this is the case, traditionalist agent uses an imitator strategy.

Varietal distribution and dynamics
SIMAS represents the evolution of diversity at both individual and global levels. At the global level, varietal richness (number of farmers cultivating a specific variety) and abundance (number of hectares by variety) evolves according to innovation strategies used by all Farmers. At the individual level, varietal diversity depends on the farm size and the equipment level. Each year, considering his equipment level, Farmer evaluates the area he can cultivate, called here farmable area. When the farmable area is greater than the cultivated area by at least 2 ha, Farmer decides to increase the cultivated area by 2 ha. Farmer then decides randomly whether or not to add a new variety. If Farmer decides to add a new variety, he determines randomly the species for which he will introduce a new variety. Farmer searches for new varieties depending on his innovation strategies and allocates the new 2 ha to the new variety.
If the farmable area is less than the previously cultivated area, Farmer reduces the cultivated area, which can lead to the abandonment of a variety.

Crop production
Farmers' main decision process in the model, crop production, is divided into two periods: the beginning and the end of the rainy season.
Period 1: Beginning of the rainy season
Farmer must estimate his production in order to cover family's needs and to save seeds. The family's needs are a function of the size of the family and need per capita for each species of crop. Using the table production matrix, Farmer estimates varieties' yields based on the beginning of the current rainy season, the type of soil, and the past rainfall. If Farmer estimates that the yield of a particular variety will be poor, Farmer changes the variety using innovation strategy. According to his equipment level, Farmer decides to increase the cultivated area or to decrease the cultivated area as described above.
Farmer then sets up production plans determining the area to be cultivated for each species, and the weight of each variety in production. The latter depends on the criteria of production and the characteristics of the cultivated varieties (**Errore. L'origine riferimento non è stata trovata.**)**Errore. L'origine riferimento non è stata trovata.**. The weight of varieties determines the share of each variety in species production. The weight of a variety is the perception on a variety divided by the sum of the perceptions on all cultivated varieties. The perception on a variety is the sum of the values of characteristics of this variety. After, farmer determines the area allocated to each variety. The area allocated to each variety is defined as follows:
*area = (weight * need)/yield*
Where *area* (ha) represents the area to allocate to the variety; *weight,* the share of the variety in the production; *need* (kg), the needs of the family concerning the species of variety; and *yield* (kg/ha),the yield of the variety.
With this information, farmer evaluate their need in seeds, which, if insufficient, he seeks through their socio-professional networks. Farmer then cultivates and manage his crops until the end of the season.
Period 2: the end of the season
At the end of the rainy season, the production of different varieties is computed as follows:
*production = (yield*area)*(intensification level – production cost)*

Where *production (tonne)* represents the total production from a plot; *yield* (t/ha), the yield of the crop; *intensification level*, the equipment level; and *production cost*, the difficulty of crop production.
The crop is harvested and stored. Farmer then determines the use of the harvests depending on his criteria, needs and the yield of the varieties (Figure 5). The harvest of each variety is divided into three parts. The first part is consumed. The quantity of the first part depends on the family's need, the variety harvest share of the total harvest of its species, and the Farmer's criteria. Its share of the total harvest of its species is determined by weighting each variety (**Errore. L'origine riferimento non è stata trovata.**). The quantity of the first part is defined as follows:
*consumed = weigth * SpeciesHarvest*
where *consumed* is the quantity of the harvest consumed, *weigth* the share of variety of the total harvest of its species, and *SpeciesHarvest* is the total harvest of the varieties of the same crop species.
The second part is stored to renew seed stocks. In order to ensure seed security, Farmer tries each year to store twice the amount of seeds he needs. Only part of the seed stock is used for production at the beginning of each rainy season, and if the harvest is satisfactory (greater or equal to medium yield), Farmer renews the seed stock for the next rainy season or later. Otherwise, the remainder of the seed stock is used the next year for crop production. If Farmer fails to renew the seed stocks of a particular variety over two consecutive years, this variety is lost and must be replaced by a new variety.

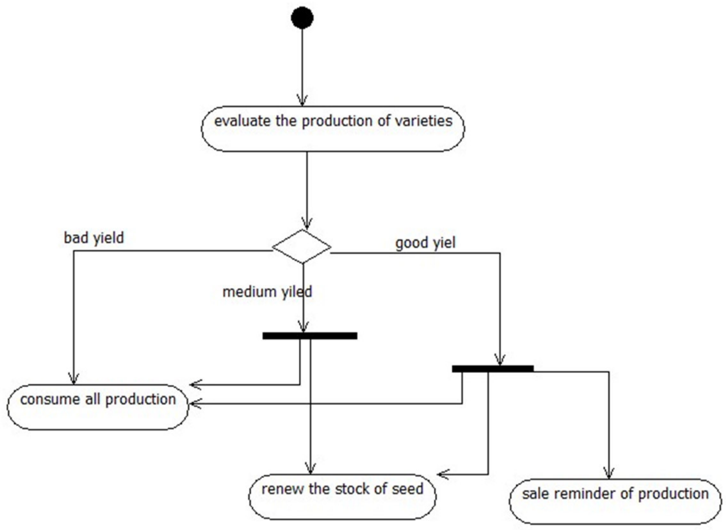

Figure 5: The UML activity diagram of production management according to the level of crop yields

Finally, the third part – the remainder - of the harvest is sold. Part of the cash from this sale is used to satisfy farmer's family cash needs and the remainder is invested in equipment.
As Farmer did at the beginning of the season, he evaluates each variety at the end of season and updates the matrix of production. This allows Farmer to learn about varieties and to select varieties adapted to climate variations.

Appendix

Table 8: The list of parameters

Input Table	Description and content	Function in the model
Climate	Defines the climate configuration of the simulated village (season duration and rainfall), the level of yields	- Initializes the climate and the levels of crop yields
Crop Species	Defines the simulated species	- Initializes the simulated crop species
Varieties	Defines the characteristics of the simulated varieties: name, color, quality of taste, conservation, transformation, quality of grain, sale and purchase price, and quantity of seed required per hectare.	- Initializes the simulated varieties
Matrix of yields	Defines the yields of varieties according to climate configuration and different types of soil	- Initializes the yields of varieties - Used by farmers to estimate the yields of varieties
Organization	Defines the types of organizations on their main roles in the system	- Initializes the characteristics of organizations
Equipment	Specifies the different level of equipment in terms of investment and cultivable area	- Defines the area that a farm can cultivate
Farmer	Specifies the typology of farmers	- Used to create and initialize the agents Farmer
Network	Defines the farmer repartition in different social and professional organization	- used to initialize the socio-professional networks of the agents
Criterions	Specifies the set of criterions of each type of farmer	- Used by the farmers to select a varieties among a group of varieties
Crop rotation	Defines for each type of farmer the crop rotation and the initial spatial repartition at the farm level	- Initializes the initial repartition of the farm
Use	Specifies for each crop specifies and type of farmer, the quantity used for consumption	
Strategies	Defines for each type of farmer the number of farmers using the different strategies of innovation	- Uses to initialize the innovativeness strategies of farmers

	(innovator, imitator and conservator)	
Simulation data		
IntroductionSchema	Schedules the period of some varieties introduction.	It allows to defines the introduction scenario
Intervention	Defines the interventions related to the improvement of the agricultural production	- Allows to schedule the proposition of interventions to farmers.
VarietieIntervention	Defines the interventions related to varieties vulgarization (supported varieties, organization supporting the varieties, type of intervention, weight, duration, frequency, duration of impact)	Allows to schedule the proposition of interventions to farmers
ClimateScenario	Defines the climates regime. A climate scenario is based on the average date of rainy season beginning, the average rainfall and their standards deviation.	
Scenario	Defines a scenario to simulate. It combines an intervention scenario, a climate scenario and an introduction schema	
Experimentation	Defines the list of scenarios to execute in an experimentation	