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Co-construction of Innovative Farming System for Crop-Livestock Integration in Dano, South-Western Burkina Faso

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DEDICATION

God makes everything well in his time, all thing comes from the Lord who allowed me to realize this thesis, fruit of long years of work. I start by giving him glory because He is the holder of knowledge and infinite power.

This thesis work is dedicated to:

- *My dear family: brothers and sisters for their multiform, moral and financial support. May GOD grant them long life and a lot of grace;*

- *My Pastor for his spiritual and moral support. God bless him;*

- *My maternal uncle who was the first to guide my steps from my admission to school;*

- *To the memory of my father and mother who departed after my admission to the university. May their souls rest in peace.*

To all the stakeholders of Dano municipality, may the findings of this research help to discuss on decision-making.

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ACRONYMS AND ABBREVIATIONS

ABM	Agent-Based Modeling
ARDI	Actors Resources Dynamics and Interactions
BMBF	The German Federal Ministry of Education and Research
IA	Integrated Assessment
CC	Climate Change
CM	Companion Modeling
CIRAD	Coopération Internationale en Recherche Agronomique pour le Développement
CAO	Cadre d'Accélération des OMD
CISV	Communauté Engagement pour Service Volontariat
Cormas	Common-Pool Resources and Multi-Agent Systems
DGMET	Directorate General of Meteorology
EWS	Early Warning System
GO	Governmental Organisation
INSD	Institut National de la Statistique et de la Démographie
IPCC	Intergovernmental Panel on Climate Change
NAP	National Climate Change Adaptation Plan (Burkina Faso)
NGOs	Non-Governmental Organisation
OMD	Objectif du Millénaire pour le Développement
PAPSA	Projet d'Amélioration de la Productivité agricole et de la Sécurité Alimentaire
PIGO	Petite Irrigation dans le Grand-Ouest
RGPH	Recensement Général de la Population et de l'Habitat
UDPC	Union Départementale des Producteurs de Coton
UNFCCC	United Nations Framework Convention on Climate Change
UML	Unified Modeling Language
UBT	Unité Bovin Tropical
VARENA/ASSO	Valorisation des Ressources Naturelles par l'Auto promotion – Association
VW	Visual Works
WASCAL	West African Science Service Centre on Climate Chance and Adapted Land Use

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ABSTRACT

In the context of climate, the rarefactions of resources, the decrease of crop yields and the increase of prices, crop-livestock integration become more and more an alternative to crop production intensification in the West of Burkina Faso. The crop-livestock contributes to the fertility management, the reduction of soil degradation, the increase of farmers' income and the increase of crop yields.

However, today many challenges emerged calling to develop alternatives strategies for crop-livestock integration. Indeed, with the population growth and the climate change, the access to the main resources on which depend crop-livestock is more and more difficult since these resources are depleting. In addition, the change of climate and the socio-economic context leaded to an important modification of roles played by crop-livestock integration in West of Burkina Faso.

The objective of this research is to develop with stakeholders' innovative crop-livestock integration in Dano. Based on the stakeholders' perception, a conceptual model integrating the various points of view have been developed. Four innovative scenarios for crop-livestock integration have been developed for the next 20 years. Finally, an agent-based model has been developed to simulate the four scenarios and recommendations developed. The resulting model is a support of decision in the fact that it allows to assess the impacts of different scenarios on crop-livestock integration. The model is a support of discussion in this way it integrates the point of view of various stakeholders and allow them to discuss about the desirable situation of crop-livestock integration.

The simulations showed an important population growth, the decrease of the per capita income and food production in the different scenarios.

Key words: Crop-livestock integration, Climate change, Participatory approach, Scenarios, Agent-based model.

RÉSUMÉ

Dans le contexte du climat, la raréfaction des ressources, de la baisse des rendements et de l'augmentation des prix, l'intégration culture-élevage devient de plus en plus une alternative à l'intensification de la production agricole dans l'ouest du Burkina Faso. L'agriculture-élevage contribue à la gestion de la fertilité, à la réduction de la dégradation des sols, à l'augmentation des revenus des agriculteurs et à l'augmentation des rendements agricoles.

Cependant, de nombreux défis émergents aujourd'hui appelant à développer des stratégies alternatives pour l'intégration de l'agriculture et de l'élevage. En effet, avec la croissance démographique et le changement climatique, l'accès aux principales ressources dont dépendent l'agriculture-élevage est de plus en plus difficile puisque ces ressources sont en train de s'épuiser. En outre, le changement de climat et le contexte socio-économique ont conduit à une modification importante des rôles joués par l'intégration agriculture-élevage à l'ouest du Burkina Faso.

L'objectif de cette recherche est de développer avec les parties prenantes, l'intégration innovante agriculture-élevage à Dano. Sur la base de la perception des parties prenantes, un modèle conceptuel intégrant les différents points de vue a été développé. Quatre scénarios innovants pour l'intégration agriculture-élevage ont été développés pour les 20 prochaines années. Enfin, un modèle à base d'agent a été développé pour simuler les quatre scénarios et faire des recommandations. Le modèle résultant est un support de décision dans le fait, qu'il permet d'évaluer les impacts de différents scénarios sur l'intégration agriculture-élevage. Le modèle est un support de discussion de cette manière qu'il intègre le point de vue des différentes parties prenantes et leur permet de discuter de la situation souhaitable de l'intégration agriculture-élevage.

Les simulations ont montré une croissance démographique importante, la diminution du revenu par habitant et de la production alimentaire dans les différents scénarios.

Mots clés: Intégration agriculture-élevage, Changement climatique, Approche participative, Scenarios, Modèle à base d'agents

CHAPTER ONE

INTRODUCTION

1.1. PROBLEM STATEMENT

The agricultural sector plays an important role in the economy of Burkina Faso. In Burkina Faso, the agricultural sector involves more than 86% of the population and contributes to 60% to rural household income (Dipama, 2014A. p.9).

However, the agriculture sector in Burkina Faso is constrained by bad climate and agro-ecological conditions. This situation hampers good agricultural production and planning of agricultural production. In addition, the increase of crash crop, the decrease of fallow periods and the pressure of the population on the natural resources leading to soil degradation and the decrease of crop yields. Also, the long-term use of biochemical fertilizers, pesticides, herbicides, etc. contributes to the destruction of soil nutrients and consequently the decrease of crop yields. In this context, the role of agricultural intensification to alleviate the negative effects of climate change is increasingly recognized. Therefore crop-livestock integration becomes more and more a relevant option to agricultural intensification in Dano (South-West of Burkina Faso).

Crop-livestock contributes to fertility management: "small farmers benefit from the integrated systems which have the potential to lead to substantial improvements of the physical, chemical and biological soil properties" (Obi, 2013. p.197). Integrating crops and livestock in the same farms help smallholder farmers to diversify the sources of income and employment. "Livestock acts as a storehouse of capital and an insurance against crop production risks, a coping mechanism against livelihood shocks as well as a vital source of dietary protein" (Rao and Hall, 2003. p.189). Rao and Hall (2003), citing Deshingkar (2002), stated that the practice of the livestock provides new jobs for women which improve their daily livelihoods. "Livestock also provides meat and milk for households and cash income that is often invested in crop production technologies. Agricultural products are used for subsistence purposes; some outputs of rangeland (wood, bush straw, and fruits), cropland (grains, crop residues, and legume hays), and livestock (animals, milk, meat, and skins) are sold. Crop residues are vital livestock feeds during the 6 to 8 months dry season, and manure enhances soil fertility for crop production" (Powell, Pearson, and Hiernaux, 2004. p.469).

However, many emerging challenges calls for the development of alternative strategies for crop-livestock integration today in South-West of Burkina Faso. Indeed, with the population growth and the climate change, the access to the main resources on which depend crop-livestock is more and more difficult since these resources are depleting and are more and more used for other activities. In addition, the change of climate and the socio-economic context lead to an important modification of the role played by crop-livestock integration in the West of Burkina Faso (MEDA, 2016. p.65). Initially, crop-livestock integration is practiced for the cultural purpose. Dagara producer does not conceive crop production without livestock (MEDA, 2016. p.65). But today, crop-livestock integration practices are used as adaptation strategies to climate change , income generation and to enhance the resilience of the population to climate change (MEDA, 2016. p.65). Additionally, the emergence of new technologies contributes to efficient nutrients recycling and energy producing; consequently, this could increase the contribution of crop-livestock integration and improves the local population's livelihoods.

Finally, in this region new actors are emerging and taking an important place in crop-livestock system. With this context of complex socio-economic and environmental conditions change, the questions that arise is how the crop-livestock system in Dano will evolve in the next 20 years? Specifically, this study addressed the following questions:

1. How to develop relevant alternative solutions for effective crop-livestock integration in Dano?
2. How the crop-livestock integration will impact the population in the future?

1.2. HYPOTHESES

The crop-livestock is a complex system characterized by various actors interacting at different scales. These actors do have not the same points of views about crop-livestock integration system nonetheless their knowledge can be complementary. But, they require to be integrated for a better understanding of the system and to develop alternative solutions that take into account the various points of view. Participatory approach is relevant to integrate the various points of view and to develop alternative solutions. The complexity of the system and the necessity to take into account the needs of future generation, requires the use of models to predict the impacts of different solutions in the future. From that, the research is based on the following hypotheses:

1. Considering many stakeholders' point of views allow development of relevant alternative solutions for effective crop-livestock integration in the context of climate change.
2. Integrating the points of views of various stakeholders concerning socio-economic and biophysical aspects of crop-livestock system, agent-based model combined with participatory approaches allow to appraise the impacts of alternative solutions for crop-livestock integration.

1.3. OBJECTIVES OF THE STUDY

The purpose of this research is to develop with stakeholders, innovative crop-livestock integration in Dano. Specifically, this study aims to:

1. identify the main stakeholders in crop-livestock system in Dano, their main issues and factors influencing the crop-livestock system.
2. co-develop with stakeholders a relevant conceptual model on crop-livestock system
3. co-develop with stakeholders innovative scenarios for crop-livestock integration.
4. co-develop with stakeholders an agent-based model and evaluate the different scenarios.

1.4. THESIS STRUCTURE

Chapter one contains problem statement, research questions, hypotheses and objectives. Chapter two provides a literature review and defines concepts, while chapter three presents materials and methods. Chapter four analyses the results through the stakeholders' engagement and simulation for crop-livestock integration. Chapter five gives recommendations and concludes the study.

CHAPTER TWO

LITERATURE REVIEW

2.1. CONCEPTS

2.1.1. PARTICIPATORY APPROACH

In discussing the participatory modeling method, d'Aquino and Bah (2014) focus on how to enable stakeholders to incorporate their own perception of environmental uncertainty and how to deal with it to design innovative environmental policies. Participatory modeling is used for different purposes. It is used by scientists to extract knowledge from the local stakeholders for a better understanding of the system. In other cases, scientists use the participatory modeling to translate knowledge to stakeholders in order to improve their decision-making based on the scientific knowledge. Finally, the participatory approach is used for knowledge sharing between scientists and local stakeholders.

Participatory approach means to take part in or to become involved in an activity in which the opinion or the idea of everybody is taken into account. Participatory Modeling is "the process of incorporating stakeholders, including the public and decision-makers and integrating scientific knowledge with local knowledge" (Voinov, 2010. p.5). Different participatory approaches have been developed to achieve the various purposes of participatory modeling. Among them, we have the Group Model Building, Mediated Modeling, and Companion Modeling. The Companion Modeling is the most relevant for modeling of natural resources management.

Companion Modeling (CM) is the brand usually associated with a stakeholder's process that involves a combination of agent-based models and role-playing games, introduced in the mid-1990s by researchers from CIRAD (France). They have supported three major principles: construction of the model with stakeholders, transparency of the process, and adaptiveness of the process with the model evolving as the problems change during the study. The fundamental objective was always to raise the awareness of the stakeholders (including scientists) about the variety of points of views and their consequences in terms of actions. Then outcomes are expected either in terms of social learning or technical and organisational innovation (Voinov and Bousquet, 2010).

Actors, Resources, Dynamics, and Interactions (ARDI) is a part of Companion Modeling approach that makes it possible to engage a broad spectrum of stakeholders in the design and development of land and water management plans. It is based on participatory workshop by gathering the various stakeholders in partnership to examine conservation of the natural resources and promoting a sustainable development (Etienne, Toit, and Pollard, 2011). Because different stakeholders do not have the same way to describe a phenomenon, then, they will not give the same perception about the actors, resources, dynamics, and interactions involved in crop-livestock integration system. These different views of stakeholders will allow to build some scenarios.

2.1.2. NOTION OF MODEL

"A model can come in many shapes, sizes, and styles. It is important to emphasize that a model is not the real world but merely a human construct to help us better understand real world systems. In general all models have an information input, an information processor, and an output of expected results" (Geoscience). The aim of the model is to ease understanding by excluding pointless components, to help in decision-making, to give details and foresee events in the future base on the observations in the past.

From what precedes, a model is an abstract description of a complex system in order to make easier its understanding. A model is built to answer a question on a complex system. For that, it is characterized by a set of variables relevant to answer to the target question. Consequently, one can build several models on a same system and each model answers to a particular question on the system.

My study is interested in modeling of the crop-livestock system. The model to develop is intended to be a support of decision and dialogue between various stakeholders.

2.1.3. SCENARIOS

Scenario is a description of another feasible version of the future but given with more details. "Scenarios are instruments for ordering people's perceptions about alternative futures in which decisions made today might play out. A scenario embodies a plausible view or perception of the future in a given year linked to conditions in the present via an internally consistent sequence of events" (Blyth, 2005.p.1). "Scenarios are not predictions or forecasts of the future, nor are they science fiction or fantasy stories constructed merely to titillate the imagination. Scenarios are stories about the future based on an understanding of the present and the factors that have shaped current conditions and sequences of events from the present to the future" (Blyth, 2005.p.2).

2.1.4. Agent-based model (ABM)

Agent-based model is composed by a set of agents interacting among themselves. Agent-based model is developed based on the assumption the global behaviour of system emerges from the individual behaviour. The individual is represented by an agent. An agent is an autonomous entity making decision in the environment that it can perceive and act on. The agents in an ABM can interact among them and take decision individually and collectively. An agent is characterized by a decision model meaning that an ABM is composed by a set of heterogeneous agents.

Taking into account the interactions between the agents and their environment ABM is relevant to represent explicitly the interactions between social and environmental dynamics and consequently the crop-livestock system. The crop-livestock system is characterized by a set of heterogeneous farmers. The farmers are different by their resources endowment, their access to land, their family structure and their strategies. They interact with their environment from crop and livestock production management.

Today, a range of platforms have been developed for the ABM development. Mostly relied on Cormas (Bousquet et al 1998), the companion modeling is a generic Agent-Based Modeling (ABM) platform dedicated to common-pool resources management. It is used by an international community of researchers willing to understand the relationships between societies and their environment. In accordance with the principles of participatory methods and serious games, many experiments developed with Cormas combine two layers of complexity: the natural dynamic of the system, simulated by the computer, and the stakeholders' interactions and decisions played by the actors. The main idea is to enable the stakeholders to interact with the execution of a simulation by modifying the behaviour of the agents and the way they use the resources (Bommel, Becu, and Le Page, 2016). The orientation of Cormas' future (when it comes to Common-Pool Resources and Multi-Agent Systems) remains the interactivity with stakeholders and local actors.

2.2. LITERATURE REVIEW

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC). This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”.

In the context of Burkina Faso, climate change is mainly caused by forest degradation through agricultural expansion, agribusiness, overgrazing, bushfires, demand for fuelwood, charcoal, etc. These are direct factors of climate. There is also indirect factors such as demography, economic, political and cultural factors that contribute to the change of climate (Kambiré et al, 2016).

Climate change (CC) has many consequences especially on agriculture and livestock sectors. Extreme events which lead to a decreasing in precipitation called drought or flooding hamper these two activities and affect their yields. But to combat the effects of climate change on these sectors many measures are being taken to adapt to the harmful effect of these changes. In agricultural sectors, the main adaptation measure is focus on soil restoration in a view to improve food production by practicing crop diversification, construction of anti-erosions dikes (stone barriers), the use of Zaï (traditional and mechanical soil restoration techniques), organic fertilization, the use of half-moons, mulching, etc. For livestock production, improve readiness for quick responses to the impact of CC, build CC resilience capacities of poor households and stimulate livelihoods in production areas (NAP, 2015). Crop-livestock integration is also one of adaptation measures adopted by the Burkina Faso to fight against CC.

The Ministry of Livestock Resources (MRA, 2015) estimated the number of cattle to 343,000 and the sheep number to 268,000 in the South-West region of Burkina Faso with annual growth rate respectively 3% and 2% (MRA, 2014) these are the herd I am interested in my study. The existing livestock production system in Burkina Faso are the following production system: traditional extensive production system in which there are transhumant production system where livestock on this system depends on natural pastures and there is no integration with crop production. And sedentary extensive system for around one day’s walk in this system livestock benefit from dry-season feeding of crop residues and brans. Also, commercial semi-intensive or semi production system which includes cattle and sheep fattening feeding them with mineral supplements and provide them good veterinary care. The livestock production system depends highly on natural pastures such as fresh grasses and some woody vegetation in dry season (Management Entity, 2017).

"An integrated farming system consists of a range of resource-saving practices that aim to achieve acceptable profits and high and sustained production levels, while minimizing the negative effects of intensive farming and preserving the environment" (Rota et al, 2010.p.1). The benefits of crop-livestock integration on socio-economic and environment include production processes enhancement, improve workforce, stability of economic factors and risk reduction, greater food security, maintaining of high level of biodiversity and reducing of environmental degradation (Moraes et al, 2014).

"The global climate is changing which may also affect agricultural and livestock production." So, this change in climate could disturb food chain especially food security. "Crop cultivation is recognized as a relatively susceptible part of the food and feed production sector that could be affected by climate change, but also livestock production could be heavily influenced. With regard to crop cultivation, variations in climatic parameters such as temperature, drought, precipitation, wind, and $CO_{2,}$ levels are projected to have notable consequences on crops in terms of changes in the demand for fertilizers and pesticides, deterioration of the quality of soils, expanding ranges of crop pests and altered transmission dynamics of insects, pests and plant diseases. Also for livestock, both harmful and beneficial effects of climate change can be hypothesized, depending on the area and circumstances. Both chemical and microbiological risks are foreseen to impair food and feed safety as a consequence of climate change" (Miraglia et al. 2009, p.1019). Climate change is a threat to food safety but the level of pathogenic micro-organisms is also relevant.

West Africa Sudano-Sahelian region is acquainted with many droughts since mid-1970 to nowadays. This situation leads the population of that zone to adapt to climate change and climate variability. Then many strategies are put in place to alleviate the impact of climate change but the adaptation comes mainly from financial support. The authors revealed that climate factors influence much in agriculture sector than livestock sector because the declining in livestock is less important than rain-fed crop production (Mertz et al, 2011).

Nardone et al (2010) have shown that high environment temperatures affect livestock production mainly in milk, meat, egg production, health issue and even in the selection of animal species. The rapid process of desertification in Sahelian countries impairs pasture areas, crop productivity and whole the livestock system production (agro-pastoralism, mixed and industrial systems). To deal with the effect of climate change on livestock production, the efforts must be put in the improvement of technologies of water management and new techniques of cooling system such as thermo-isolation.

It is recognized that when the United Nations developed its Convention to Combat Desertification to facilitate greater knowledge exchange between scientists and policymakers, analyses have failed to consider the powerful informal actions that scientists can take to allow their research to inform evidence-based international policy (Stringer and Dougill, 2012). Faced with the limited impact of scientific knowledge on prevailing drylands policies, experts started using community participation (d'Aquino and Bah, 2014).

Hinrichsen (2010) said that the integration of livestock and crop production provides many benefits to farmers. Both livestock and crop production exchange their products with each other. Crop production gives crop residues which livestock can utilise for feeding or in the processing of making compost. Beneath, the contribution of livestock leads to the conservation or improving the soil fertility, through the transfer of nutrient (excrement and urine) from animals to the cropland. Livestock can be used for tillage (cattle) for crop intensification as well for transportation.

Scoones and Wolmer (2000) hold that mixed farming which involves the integration of crop and livestock on a single farm increases the productivity and is sustainable for small-scale African farming system. Besides technological developments, the crop-livestock integration is promoted through extension effort and development programmes. Previous studies on crop-livestock integration have examined the relationship between a set of "drivers" (e.g., changes in population and market access) and a set of "outcomes" (e.g., mixed farming) but have failed to establish the link between drivers and outcomes, because alternative ways lead to different outcomes for different people. In my study we are interested in the interactions between drivers and outcomes. For that, my approach is based on modeling approach. The use of modeling and sensitivity analysis, allows to assess the impacts of different factors on the dynamics of the system. Using particularly the ABM allows to assess how the different drivers impacts the different farmer types in different scenarios and to formulate adequate policies for different groups of farmers.

CHAPTER THREE

MATERIALS AND METHODS

3.1. GEOGRAPHY OF THE STUDY AREA

Burkinabe land is located in the heart of West Africa, Burkina Faso is a landlocked country without sea landing. With an area of 274,000 km², it is one of the African countries with many neighbours namely Mali in the West and the North, Niger in the East and Cote d'Ivoire, Ghana, Togo and Benin in the South.

The study area is situated in the south-western of Burkina Faso especially in the South-West region of the country: the Dano municipality. The South West region covers an area of 16,318 km² or 6% of the national territory. It is limited to the east by the Republic of Ghana and the Central West Region, to the north by the Hauts Bassins and Boucle du Mouhoun regions, to the west by the Cascades region and to the south by the Republic of Côte d'Ivoire. The terrain is very rugged and consists in its majority of plateaux whose average altitude reaches 450m (INSD, 2009). The annual amount of rainfall in this locality is better than other parts of the country. The soil type in this area supports vegetation growth.

Dano is the capital of the province of Ioba which belongs the region of South-West. The municipality of Dano is located between 11°and 12° north latitude and between 3° and 4° west longitude. This town is distant at 117 km from Gaoua (capital of South-West region). It has seven (07) sectors and twenty-two (22) villages and limited by other six municipalities as the communes of Koti and Fara to the north, the commune of Dissin to the south, the commune of Koper to the east and the communes of Guéguéré and Oronkua to the west. In Dano the number of households is estimated to 8,438 households with an overall population of 46,557 whose 22,194 men and 24,363 women (INSD, 2015). The main activities of the population in this municipality are respectively agriculture, livestock farming, trading and craft (Meda, 2016.p.50). Nowadays, the rise of gold is occupying an important place in the life of people.

Finally, the study area, the municipality of Dano is sited in the Sudano-Guinean climatic zone with rainfall of more than 1000 mm per year. The rainy season lasts from May to October and the dry season lasts from October to May. During the year, generally the extreme temperature swings from 12° C to 38° C (Géographie du Burkina Faso, 2008).

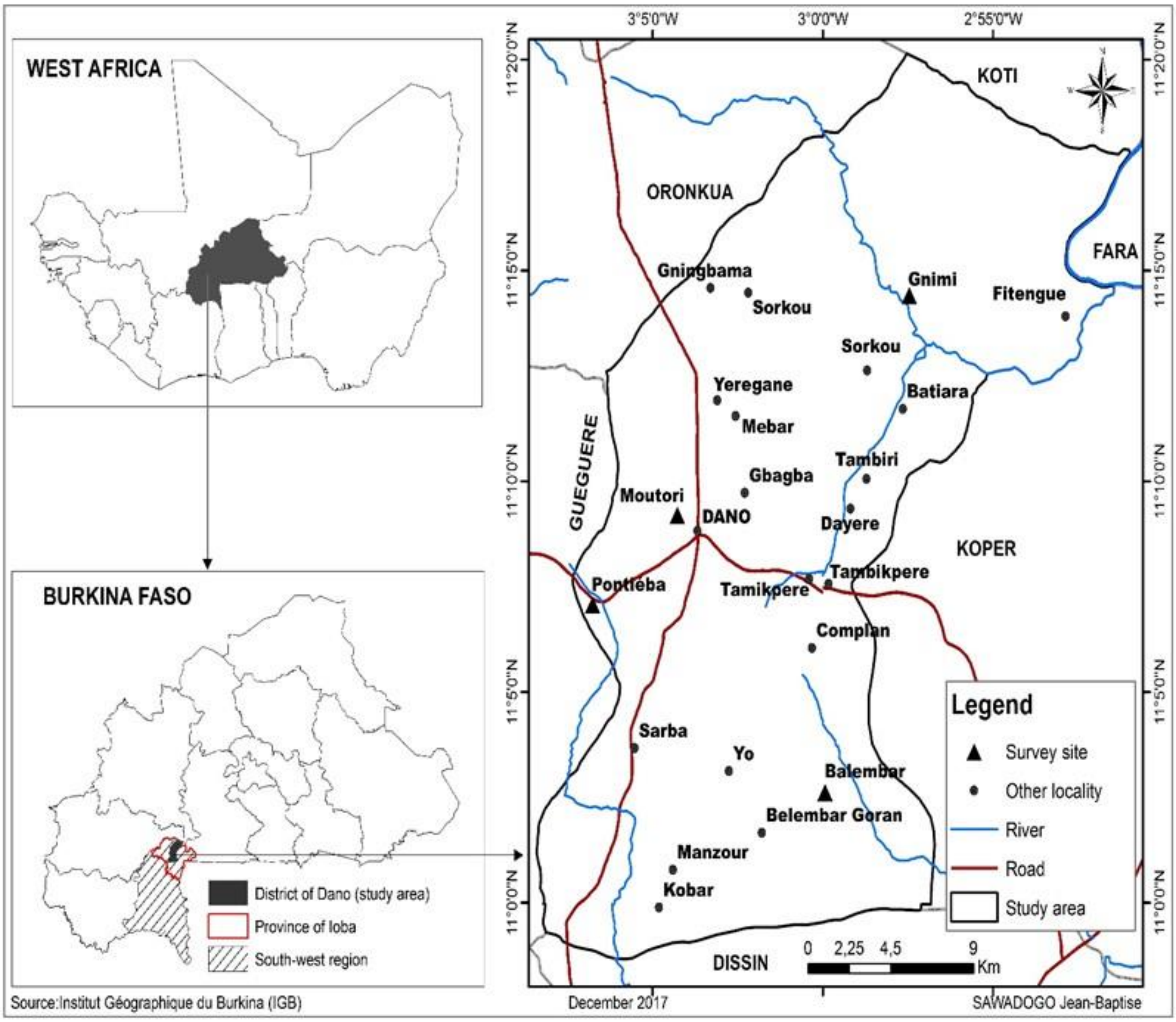

Figure 1: Municipality of Dano/Administrative card

3.2. METHODOLOGY

The study approach is based on the participatory approach combined with agent-based model. In this study, we used the participatory modeling to integrate knowledge from researchers, farmers and policy makers. The approach involved farmers, researchers from different disciplines and policy makers. To achieve this study two workshops were organized. The first workshop concerned the development of innovative scenarios for alternative crop-livestock integration. The second workshop concerned the validation of the main results and the model by the stakeholders.

3.2.1. STAKEHOLDERS IDENTIFICATION AND MAPPING

The methodology was based on the participatory approach involving both the researchers and social actors (decision makers, NGOs, farmers, etc.). Firstly, the main stakeholders were identified through previous study (Meda, 2016). The relationships and interactions between the various stakeholders were described using the ARDI approach. After that the main issues related to the land use management in Dano were identified and scored by the stakeholders. Finally, the stakeholders identified the drivers or factors of change which impacted and will impact crop-livestock integration in Dano.

3.2.2. SCENARIOS DEVELOPMENT

The objective was to develop with stakeholders innovative scenarios for crop-livestock integration for the next 20 years. First, a review of literature allowed to identify ten (10) main drivers or factors of change of crop-livestock management in Dano for the past 20 years. During the first workshop, the main drivers or factors were validated and the most relevant drivers of change selected. The factors selected by the stakeholders were scored according to their points of view. Secondly, with the stakeholders, the main factors for the next 20 years were identified and scored. Based on their selection, the two most important and uncertain drivers of change have been selected. Finally, using the two most important and uncertain factors, four scenarios have been identified and described with the stakeholders. The description of scenarios by the stakeholders consisted in a qualitative evaluation of the various factors in the different scenarios. Specifically, the objective was to define how the different factors will evolve in the four scenarios. Based on that, a textual description of the scenarios is provided. Finally, the impacts of different scenarios on the different issues previously identified are assessed in order to inform stakeholders how the scenarios could contribute to their respective objectives.

3.2.3. DATA ANALYSIS AND MODELING

From the description by the stakeholders and the developed scenarios, a conceptual model was built using the Unified Modelling Language. The conceptual model was transformed to an agent-based model using Cormas platform (Bommel et al, 2016; Le Page, 2001; Bousquet, 1998.). The agent-based model is developed to integrate stakeholders' points of view and their decisions making regarding the crop-livestock integration and to simulate the main scenarios previously identified. The resulting agent-based model represents the crop-livestock system at different scales: plot, farm and local level. As processes, the dynamics of the model take into account the population dynamics, the crop production, the livestock and pasture management and the climate dynamics.

Based on the structure of the conceptual model, the model is developed through scenarios, where data have been collected from different sources. After that simulations have been achieved to assess the impacts of the scenarios on population, cereal and cotton production, and income generation.

Several tools were used in this study namely Excel 2013 which allowed to make tables, computation, and graphics; Word 2013 is also used to write of the document and make some tables and graphics. ArgoUML v0.32.1 is the software that was used to create causal diagram with the factors influencing crop-livestock integration and class diagram which represents the concepts of the system. The classes have been defined over indicators given by the stakeholders during the field work. Finally, Cormas vw7.6nc is the software used to develop the model.

3.2.4. DATA COLLECTION

Data from different sources were used in this study. Also, data from existing study have been used (Meda, 2016). Existing data from previous survey (OMD (CAO), 2012 and Chambre d'Agriculture Indre, 2011) were also used. In addition, data was collected from the database of the Institut National de la Statistique et de la Démographie (INSD, 2012).

The collected data concerned the farmer typology, crop and climate. Three types of farmers were taking into account in the model: small farmer, medium farmer and great farmers according to the typology defined by Meda (2016). The socio-economic characteristics of these farmers were captured from Meda (2016) and from INSD database. INSD uses a farmer typology based on four types of farmers: Very Poor, Poor, Medium and Rich. In this study, the very poor and poor farmers have been grouped to define the socio-economic characteristics of small farmers. The socio-economic characteristics of Medium and Great farmers are those of the INSD Medium and Great farmers. The socio-economic characteristics concerned the family size, the farm size, the per capita cultivated area for cereal (sorghum, maize and millet) and cotton, the per capita cereal consumption, the per capita income and expenditure, the herd (cow and sheep) size (Table 1).

The climate data defines the precipitation in bad, medium and good climates. This information was defined based on interview of farmers and experts. The interview sought to know the amount of precipitation for the past five years. Based on that information and the annual precipitation of the five years, we determined the average precipitation in bad, medium and good climate context (Table 2).

As the farmer type corresponds to an intensification level, the crop yields are based on the farmer typologies and climate configurations (Table 3; Table 4 and Table 5). Initially, the average yields of crops were defined based on the production during the last five years. The average crops yields were considered as the crops yields for the medium farmers in medium climate configuration. Based on that, the crops yields for the other farmer types in different climate configurations were defined. Then, the crop yields of small farmer in medium climate configuration is -50 of the medium farmers in medium climate configuration and the crop yields of great farmer in medium climate configuration is +50% of the medium farmers in medium climate configuration. For each farmer type, the crop yields in bad climate configuration are -50% of the crop yields in medium climate configuration, and the crop yields in good climate configuration are +50% of the crops yields in medium climate configuration.

Table 1: The different types of farmers in the model

	Small Farmer	Medium Farmer	Great Farmer	Sources
Family size	10	13	15	INSD (2012)
Farm size (ha)	5	11	25	INSD (2012)
Herd size (UBT)	0	7	39	INSD (2012)

Per capita cereal area cultivated (ha per capita)	0.25	0.35	0.43	INSD (2012)
Per capital cotton area cultivated (ha per capita)	0.18	0.25	0.18	INSD (2012)
Per capita annual income (F CFA per capita)	65 000	100 000	200 000	INSD (2012)
Per capita cereal need (kg per capita)	190			CAO (2012)
The population growth rate (%)	1.8			INSD (2012)
The livestock growth rate	0.019			INSD (2012)
Animal excretion rate (kg-DM/kg/Hour)	1			
The animal grazing rate (kg DM/Hour)	0.4165			CHAMBRE D'AGRICULTURE INDRE (2011)

Table 2: Annual precipitation in different climate configurations

	Bad	Middle	Good	Source
Annual precipitation (mm)	800	1000	>1100	Field work

Table 3: The crop yields (tonne/hectare) in the different climate configurations for the small farmers

Crop type	Bad precipitation	Medium precipitation	Good precipitation	Source
Sorghum	0.24025	0.4805	0.961	INSD (2012)
Maize	0.2865	0.573	1.146	
Millet	0.159	0.318	0.636	
Cotton	0.26475	0.5295	1.059	

Table 4: The crop yields (tonne/hectare) in the different climate configurations for the medium farmers

Crop type	Bad precipitation	Medium precipitation	Good precipitation	Source
Sorghum	0.4805	0.961	1.922	INSD (2012)
Maize	0.573	1.146	2.292	
Millet	0.318	0.636	1.272	
Cotton	0.5295	1.059	2.118	

Table 5: The crop yields (tonne/hectare) in the different climate configurations for great farmer

Crop type	Bad precipitation	Medium precipitation	Good precipitation	Source
Sorghum	0.961	1.922	3.844	INSD (2012)
Maize	1.146	2.292	4.584	
Millet	0.636	1.272	2.544	
Cotton	1.059	2.118	4.236	

3.3. DEVELOPMENT OF AN AGENT-BASED MODEL FOR CROP-LIVESTOCK SYSTEM

3.3.1. INTRODUCTION

The goal of this section is to describe the agent-based model developed as a support of decision and dialogue between stakeholders. Specifically, this agent-based intends to integrate the points of view of various actors and to assess the impacts of different scenarios. The conceptual model is based on the stakeholders' points of view and the identified scenarios. This section presents the aim of the model, the integrated processes, the agents and the dynamics structure of the model.

3.3.2. THE AIM OF THE MODEL

The aim of this model is to simulate the alternative scenarios for innovative crop-livestock integration in Dano. The model is a support that eases the understanding of crop-livestock integration, allows decision-making and helps to have an overview of the future events. It is a support of decision used to assess the impacts of different scenarios on crop-livestock integration. The model is a support of discussion in this way it integrates the point of view of various stakeholders and allows them to discuss about the desirable situation of crop-livestock integration.

3.3.3. THE SCALES OF ANALYSIS

The model is a multi-scale model. The multi-scale representation provides a relevant description of the stakeholders' decisions making and various processes that occur at different scales of analysis. For example, farmers take decision at plot, farm and village levels and the policies makers take decision at the system level. From what precede, one scale is not sufficient to represent the dynamics of crop-livestock system. The conceptual model of my system is based on the following scales:

- Plot level: the farmer manages the cultivated crops at the plot level. According to the biophysical characteristics of a plot (soil, topology, etc.) and cultivated crop, the farmer decides the appropriate management approach.
- Farm level: it represents the domain of the farmer and delimits its decision-making.
- Local level: it represents the global system where the interactions between actors take place.

3.3.4. The processes

At the different scales of analysis, various processes are integrated to provide a relevant representation of the system (Figure 6). So at the plot level, the model takes into account the biomass production, the crop production, the fertility management and the pasture. At the farm level, the interest is in household population growth, the crops management, livestock management, food and cash management. Finally, at the local level, the model is interested in crop products commercialization in the market, the institutional support and climate dynamics.

Table 6: The process at different scales

Scale	Processes
Plot	- Biomass production - Crop production - Fertility management - Pasture
Farm	- Household population growth - Crops management - Livestock management - Food management - Cash management - manure management - Crop residues management
Local (watershed) level	- Pasture - Input and output market - Institutional support - Climate dynamics

3.3.5. THE STATE AND VARIABLES OF THE MODEL

3.3.5.1. Agents

Three types of agents define the structure of the model (Figure 2): Farmer, Herd and Climate. The farmer represents the dynamics of a whole farm. It is characterized by its type, the family size, the herd size, the cash, the cereal stock, the level of equipment. Tree types of farmers are represented in the model: **Small Farmer**, **Medium Farmer** and **Great Farmer** (Table 1, Figure 2). The Small Farmer has a family size of 10 persons, 5 ha of farm with 65 000 FCFA year per capita as per capita income. As to the Medium Farmer, it has a family size of 13 persons, 11 ha of farm and 100 000 FCFA year^{-} per capita as per capita income. Finally, the Great Farmer with a family of 15 persons, has 25 ha of farm, 39 UBT of livestock. With, 200 000 FCFA year per capita as income, the Great Farmer is the richest farmer.

The second type of agent is the **Herd**. A Herd represents a group of animal belonging to a farmer. It is characterized by its size, and the distance of pasture.

The last type of agent concerns the **Climate**. Climate computes the precipitation of the whole system.

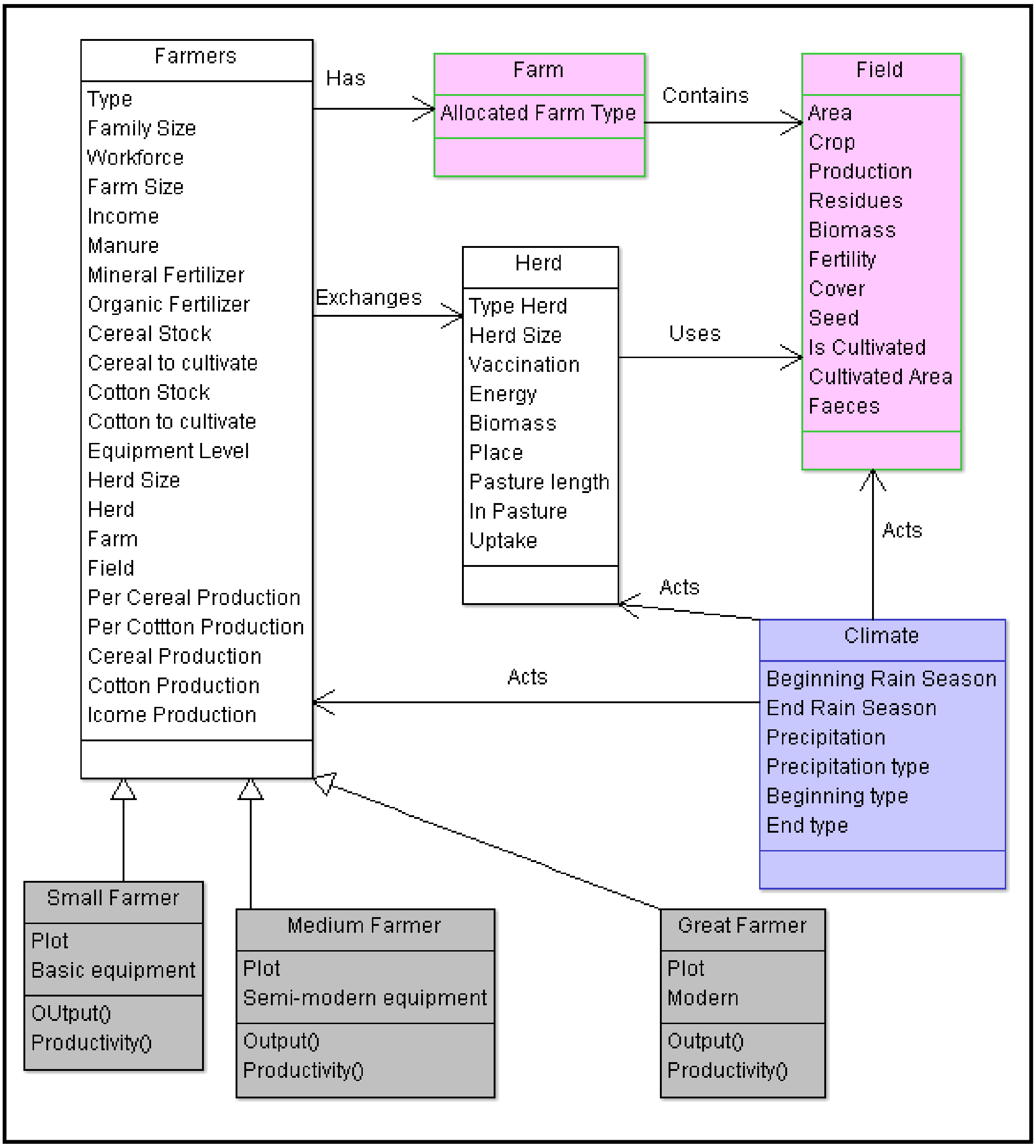

Figure 2: The UML representation of structure of the model

Source: Field survey

3.3.5.2. The spatial organisation of the model

The model is spatialized to represent the spatial dynamics of the environment. The environment is represented by a set of cells representing the elementary spatial entities of the model. A cell represents a field or a piece of forest (Figure 3). Each cell is characterized by its occupation (forest, cereal, cotton and fallow), the total biomass and the crop production (for the fields). The cells are aggregated to form farms (Figure 3).

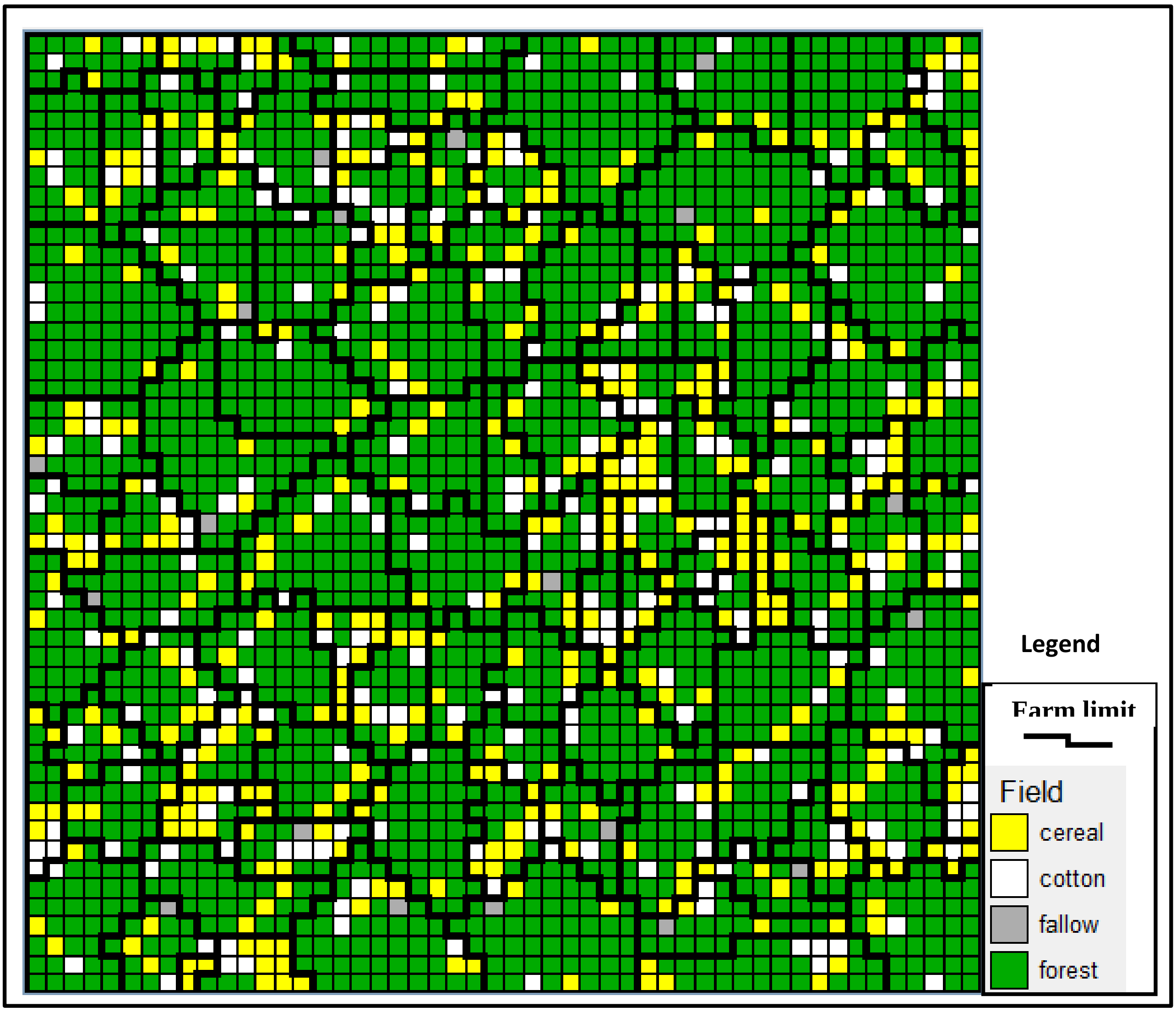

Figure 3: Spatial organisation of the model

3.3.6. THE MODULES OF THE MODEL

The structure of the model is composed by four different modules: demography, crop production, livestock management and the climate module.

3.3.6.1. The climate module

The climate module computes randomly the annual precipitation. Based on the computed annual precipitation, the type of climate configuration is determined. Three types of climate configuration are defined in this study: bad, middle and good. For each climate configuration, the corresponding annual precipitation is specified based on stakeholder's point of views. Stakeholders have been surveyed to know according to their knowledge to the annual precipitations in bad, middle and good raining.

3.3.6.2. Demography module

The demography module represents the annual population growth. The global population depends on the farmers' household individual growth. Then, each year the household size increases by the population growth rate as follows.

$$\boldsymbol{size} = size * growthRate$$

Size is the household size, size is the number of the family and growth rate the population growth rate.

3.3.6.3. Crop production module

Farmers produce cereal and cotton to meet their respective food and cash needs. Then, at the beginning of the raining season farmers define the area to cultivate for each type of crops. The area to cultivate depends on the per capita cultivated area for each type of crop and the farmer family size. The per capita cultivated area depends on the farm type (Table 1). It is calculated as follows:

$$\boldsymbol{area} = perCapitaArea * size$$

Area is the area to cultivate for a specific crop, perCapitaArea is the per capita area to cultivate for a specific crop and size is the farmer family size.

Based on the area to cultivate for each crop, the farmer selects the fields to cultivate, sows and manages them until the crop maturity. Then, the farmer harvests the fields. The crop yields are dependent on the level of intensification (farmer type) and the annual precipitation (Table 3, Table 4 and Table 5).

After the crop harvest, the farmer stocks a part of the cereal production for consumption and the rest is sold. As for the cotton, all the production is sold.

Once the crop is harvested, the crop residues are harvested as compost for organic fertilization, or are used for livestock feeding.

3.3.6.4. Livestock management module

Livestock management module represents the type of livestock practiced by farmers and also the way manure is managed in the field. Manure is associated with crop residues or straw to make compost used in the improvement of the soil fertility.

The Herd moves to seek forage. The herd moves preferentially to the place with high available forage. The pasture is sought per daily time step and the herd goes to the pasture every day and comes back to the paddock when their food need or the maximal pasture length is reached.

3.3.7. CONCEPTS

3.3.7.1. Adaptation

The farmers and livestock adapt their behaviour according to the climate configuration. For instance, farmers determine the area to cultivate according to the climate configuration. In addition, the length of pasture depends on the available biomass and its growth is influenced on the climate configuration. During the dry season the pasture length is longer than in raining season.

3.3.8. PARAMETERS OF THE MODEL

The parameters of the model have been defined to target the various scenarios previously identified. The parameters define the initial population structuration, the socio-economic condition of the farmers and the climate configuration depending on the scenarios (Table 7).

Table 7: The main parameters of the model

Description of the parameters	Sources
Socio-economic characterization of farm types (family size, farm size, income, equipment level, herd size, etc.)	
Number of small farmers in the population	INSD (2012)
Number of medium farmers in the population	INSD (2012)
Number of great farmers in the population	INSD (2012)
Population growth rate	INSD (2012)
Farmer income per capita	INSD (2012)
Cultivate area per capita	INSD (2012)
Per capita cultivated area for cereal	INSD (2012)
Per capita cultivated area for cotton	INSD (2012)

Animal grazing rate	CHAMBRE D'AGRICULTURE INDRE (2011)
Livestock growth rate	INSD (2015)
Maximum pasture length	
Per capita cereal needs	CAO (2012)

As output, the model produces data on the population, the livestock, the per capita cereal production and cotton production, and per capita income production (Table 8).

Table 8: The output of the model

Output	Description
Population	Total population in the model
Livestock	Animal population
Cereal production	Total cereal production
Cotton production	Total cotton production
Income	Total income
Farmer type cereal production	Total cereal production by farm type
Farmer type cotton production	Total cotton production by farm type
Farm type income	Total income by farm type

3.3.9. THE OVERALL DYNAMICS OF THE MODEL

The model is a monthly time step. At each time step, the model schedules the livestock pasture. As the pasture is daily time step, at each time step, the model simulates the daily pasture dynamics 30 times. At the beginning of the year, the model computes the beginning and the end of the raining season. Based on the information of the beginning of the raining season, farmers allocate crops to the different plots. At the end of the raining season, farmers harvest the crops and stock their production. The crop yield is function of level of equipment and the precipitation. After, the harvest of the production, a part of the production is consumed and the rest sold.

3.3.10. Conclusion

This chapter described the modeling approach and the study site. The approach is based on the participatory modeling approach involving stakeholders from different sources: farmers, NGOs, Governmental organization (GO) and scientists. All the steps for the workshop can be seen in Annex 2. The modeling approach is based on agent-based modeling. The collected data is described. The main of crop-livestock at plot, farm and local level. The main agents of the model concern the farmer, herd and climate. As processes, the model takes into account the crop production, the pasture, the climate dynamics and the demography dynamics. The parameters of the model have been defined to allow the specification of the scenarios in the model and to simulate them. The next chapter concerns the stakeholders’ engagement in my modeling approach.

CHAPTER FOUR

RESULTS: STAKEHOLDERS ENGAGEMENT AND DEVELOPMENT OF INNOVATIVE SCENARIOS AND SIMULATION FOR CROP-LIVESTOCK INTEGRATION

4.1. INTRODUCTION

The objective of this chapter is to develop with stakeholders innovative scenarios for crop-livestock integration in the study site. For that, the chapter presents the actors, their relationships and the main issues. In addition, the factors of change of crop-livestock integration based on which scenarios are developed are also presented.

4.2. THE MAIN STAKEHOLDERS OF CROP-LIVESTOCK INTEGRATION

Several stakeholders are involved in the crop-livestock system (Table 9 and Figure 4) and actors were identified in two categories: direct and indirect actors (Table 9). The direct actors are producers (farmers and breeders), state technical services coming from different ministries as Agriculture, Livestock and Environment.

These ministries are helped in their tasks by Technical Partners (Varena/asso, CISV, and PIGO). Also, farmers' organizations (UDPC and other agricultural sectors, etc.) play important role as they organize the farmers and defend their interests.

As to indirect actors, they are consumers, traders, transporters, customary authorities and technical partners (PAPSA, Tree Aid, etc.).

Table 9: The main actors of the system

Direct Actors	Indirect Actors
Farmers	Consumers
Breeders	Transporters
State Technical Services (Agriculture, Livestock, Environment)	Traders
Technical partners (Varena/asso, CISV, PIGO)	Transformers
Producers Organizers (UDPC, and other agricultural sectors etc.)	Technical partners (PAPSA, Tree Aid, etc.)
	Local collectivities
	Customary authorities

To achieve their respective goals, the various actors interact among themselves to exchange information (advise, support) and resources (crop residues, compost, equipment, manure, etc.). The global dynamics of the system emerge from their interactions (Figure 4).

First, farmers and breeders exchange their products to benefit from each other (crop residues, thatch, compost, traction, manure, etc.). Farmers allow breeders to pasture their animals on their fields to consume the crop residues and benefit of the animal manure that contribute to the field fertilization. In addition, farmers use the animal manure provided by the breeders to produce compost for the field fertilization. Thirdly, cotton growers interact with Departmental Union of Cotton Producers to defend and represent the interests of other nearby this union. In return the union informs, trains and sensitizes cotton growers how to use adapted crop varieties and appropriate pesticides for cotton production. Fourthly, traders purchase directly from farmers their products and in return farmers buy the same products from them in the market. Fifthly, transporters transport the farmers and traders products to different places (home or market).
Furthermore, technical partners finance and support technically growers and herds in their practices. Finally, customary authorities are responsible for reconciling farmers and breeders in case of conflicts or misunderstanding between these actors.

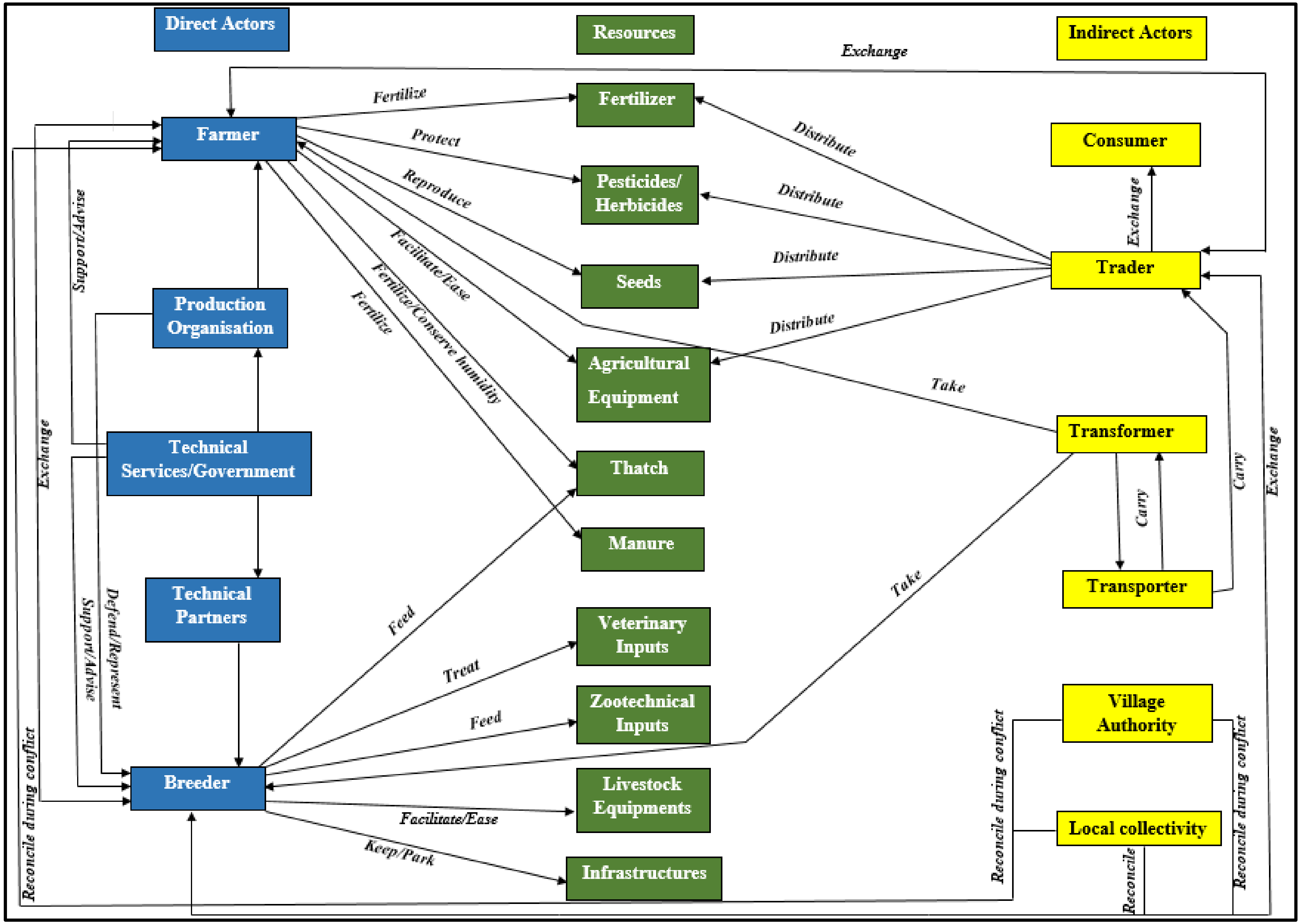

Figure 4: The actors and their interactions description using ARDI

Source: Field survey

4.3. THE MAIN ISSUES TARGETED BY THE STAKEHOLDERS

The main issues have been identified by stakeholders in Meda (2016). The objective here is to validate and score the different issues by the stakeholders (Table 10). During the workshop, three new issues were added to the initial list of issues: “regulate and comply with the laws of gold mining”, “the extension of the bio-digester” and “the subsidization of the energy”. Each issue was scored from 1 to 3 according to their importance from the stakeholders points of view (Table 10).

Table 10: The mains issues to reach by crop-livestock integration

Issues	Importance
Social issues	
Mitigate land disputes	**3**
Promote co-existence between farmers and herders	**2**
Improve food security	**3**
Reduction of workload	**2**
Reduction of rural exodus	**1**
Strengthening resilience to climate change	**3**
Diversification of sources of subsistence	**2**
Regulate and Comply with the Laws of Gold Mining	**3**
Economic issues	
Increase in farm income	**3**
Increase in livestock income	**3**
Reduction of expenditures related to the use of chemical fertilizers	**3**
Stimulating economic growth	**3**
Environmental issues	
Increase soil fertility	**3**
Reduction of soil degradation	**3**
Extension of the bio-digester	**3**
Energy subsidy (bottled gas and improved stoves)	**2**

3: very important; 2: intermediately important; 1: less important; 0: not significant

4.4. FACTORS INFLUENCING CROP-LIVESTOCK INTEGRATION

To identify the main factors that influence the crop-livestock integration, the stakeholders were asked the following questions:

- According to your knowledge and experiences, what factors have impacted the crop-livestock system during the last past 20 years?
- According to your knowledge and experiences, what factors will impact the crop-livestock system in the coming 20 years?
- Among the factors that will impact the crop-livestock integration in the future, what are the uncertainties related to the different factors?

Stakeholders identified two categories of factors of change that have impacted crop-livestock integration during the past 20 years: environmental and social factors. From the environmental point of view, the main factors are weather uncertainty that is a natural phenomenon and space sharing which alludes to the availability of the cultivable land. From the social point of view factors, the main factors are: lightening the work of agriculture, satisfaction of cultural values and institutional support.

These factors have been scored according to the importance of their impact on crop-livestock integration (Table 11). However, in our study only the most important factors have been identified by the stakeholders.

Table 11: The factors that impacted crop-livestock integration in the past

Factors	**Importance**
Environmental factors	
Weather uncertainty (climatic hazards)	**2**
Space sharing	**3**
Social factors	
Lightening the work of agriculture	**3**
Satisfaction of cultural values	**3**
Public institution advised crop-livestock integration	**3**

3: very important; 2: intermediately important; 1: less important; 0: not significant

As factors that will impact the crop-livestock integration in the future (for the next 20 years), the stakeholders identified demography, climate change, profit research, agriculture intensification and institutions (Table 12). Among these last factors, stakeholders identified the agricultural intensification and the institutional support are the two most uncertain factors.

Table 12: The factors that will impact the crop-livestock integration in the future

Factors	**Importance**	**Uncertainty**
Demography	**3**	
Climate change	**3**	
Profit searching	**2**	
Agricultural intensification	**3**	✓
Institutional support	**3**	✓

3: very important; 2: intermediately important; 1: less important; 0: not significant

4.5. THE SCENARIOS FOR CROP-LIVESTOCK INTEGRATION

Four scenarios are identified based on the two most important and uncertain factors: the institutional support and crop intensification (Figure 5). The institutional support means all the measures which the government put in place to assist or support farmers and breeders such as the subsidization of fertilizers, assistance or advice to farmers and breeders through their agents on the field, construction of warehouse, etc. While crop intensification is the modernization of the agriculture using less input (land) to get much crop yield through fertilizers and mechanization. When the two factors institutional support and crop intensification are very high that means the crop-livestock integration is strong. But the case that one of the factor is very low that lead to weak crop-livestock integration.

Scenario 1 is characterized by a very high institutional support and low crop intensification. This scenario has a few impact on crop-livestock integration. **Scenario 2** is characterized by a very high crop-livestock integration in the context of high institutional support and high crop intensification. **Scenario 3** is a weak crop-livestock integration with a high crop intensification and low institutional support. Finally, **Scenario 4** is a context of null crop-livestock integration. In this scenario, crop intensification and institutional support are very low.

The fourth scenario has been cancelled because actually it does not make sense (Table 13 and Table 14). This is because there is no decrease in demography. Furthermore, there cannot be a system where all the structures of development fail. At least one of the structure is going to operate even it does not attain its purposes. However, the changing in climate and weather uncertainty are known by African countries but in this scenario all the factors are decreasing. So, that could not be realistic in the next 20 years.

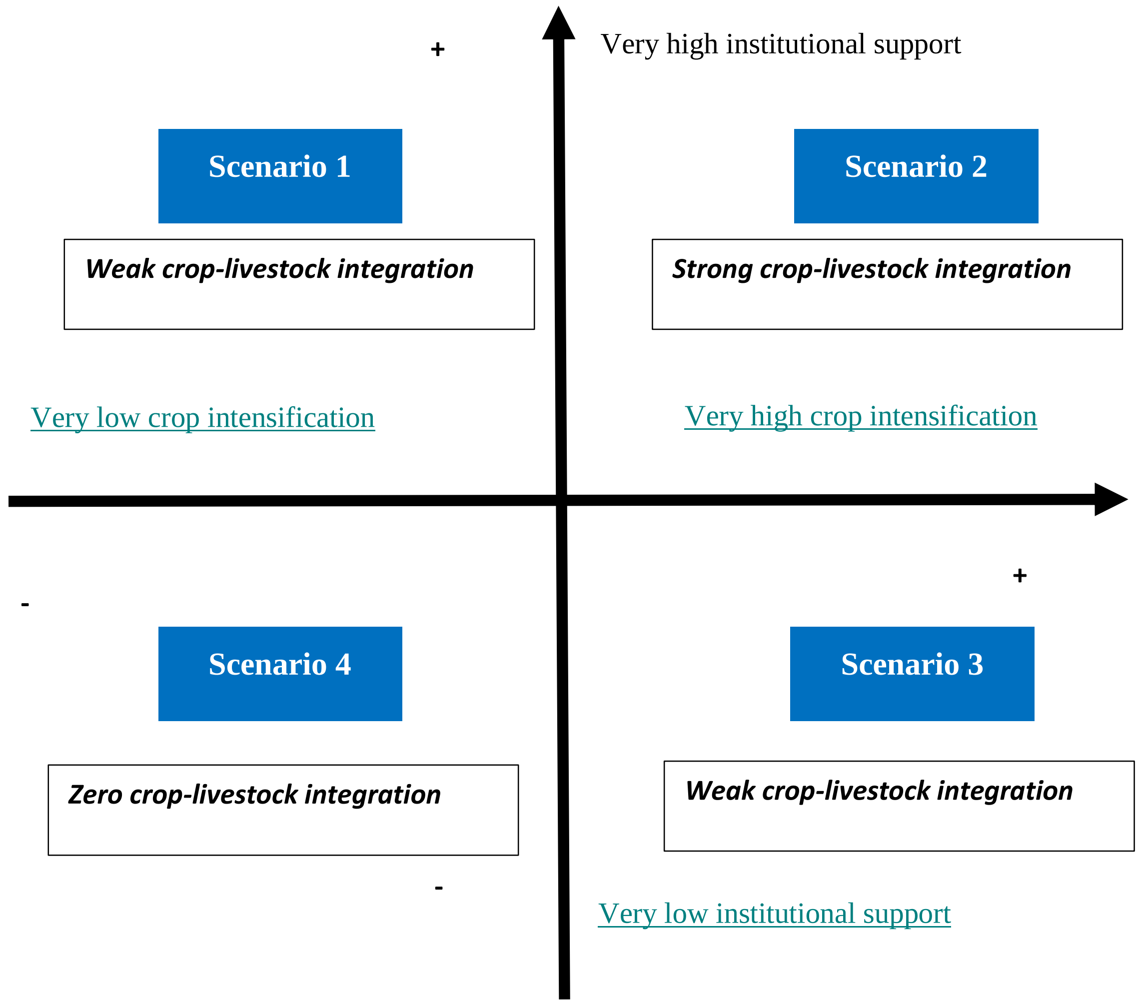

Figure 5: The main scenarios of crop-livestock integration

4.5.1. DESCRIPTION OF THE SCENARIO 1

Scenario 1: ***Weak crop-livestock integration*, in the case there is high implication of institutions and weak practice of agricultural intensification.**
The population is increasing in medium way leading to the high land demand and high land sharing (Table 13). The high land demand and the low crop intensification (the crop land is expanding) increase a) conflicts between farmers and herders due to the scarcity of land and resources and b) competition between crop production and livestock breeding (Table 14). But the institutional support that is important to mitigate these conflicts. And livestock management continues to be a traditional practice. From the environmental point of view, the forest degradation is rapid due to the rapid population growth and high land demand. That leaded to a rapid expanding of crop land, soil degradation and decrease of crop yields. As the agricultural production is degrading, the food security and farmers revenue are hampered.

Consequently, farmers diversify their activities to improve their revenue and life standard. The increase of the population leading to the decrease of per capita labour contribution to the agriculture labour favours the diversification of activities. In addition, to compensate the balance in farming system, farmers try to get money through gold seeking especially during the dry season because the authorities defend gold exploitation in rainy season.

4.5.2. DESCRIPTION OF THE SCENARIO 2

Scenario 2: ***Very high crop-livestock integration*, in the case there is high implication of institutions and high practice of agricultural intensification.**

This situation is extreme in this scenario (Table 13 and Table 14). The population growth is very important. In addition the climate change is accentuated. As a consequence of this climate change, Dano is affected by a high weather uncertainty. The high population growth, climate change and high weather uncertainties lead to an increase of land sharing and land use. The climate change combined to weather uncertainties negatively affects the crop yields. To face with the decrease of crop yields, farmers increase the crop land leading to arable land scarcity and high crop intensification, rapid soil degradation and high Greenhouse Gases (GHG) emission.

At the same moment, due to the high institutional support, livestock management becomes more and more modern and contributes to the agricultural intensification. The modernization of livestock management favours the adoption of energy production technologies. Then, the bio-digester technology is adopted by a large number of farmers.

From the economic point of view, farmers diversify their activities to face with the degradation of agricultural production. The diversification of activities is favoured by the decrease of the per capita labour contribution to the agricultural production due to the increase of the population. In addition, cash production is developing more and more thanks to the institutional supports. In fact, the institutions provide important supports to farmers to face with the degradation of agricultural production and negative impacts of climate change. In addition, they created market opportunities at local, national, regional and international levels.

From the cultural point of view, the evolution of the demography impacts on the cultural values are important because the city life influences the local life and that provokes the dropping of cultural requirements by the people.

4.5.3. DESCRIPTION OF THE SCENARIO 3

Scenario 3: ***Weak crop-livestock integration*, in the case there is weak implication of institutions and high practice of agricultural intensification.**

The population growth is slow and the land demand is low (Table 13 and Table 14). Consequently, in this case the space sharing allows the avoiding of land issues. The population is aware of the preservation of the environment. Then, farmers are adopting crop intensification technologies. The agricultural intensification changed the trends of deforestation and soil degradation. As the land use level is low, the natural resources are stored in natural way which is resources used for the livestock management. From what precedes, the conflicts related to land and resources access and the conflicts between farmers and breeders are considerably reduced.

From the social point of view, the youngers are staying in their localities to participate in the development of their communities and increase their life standard leading to an important reduction of rural exodus. Evolving in a context of low institutional support population makes efforts to reach food security without any institutional support.

Table 13: The evolution of the crop-livestock factors in the 4 scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Demography	+ +	+ + +	+	-
Climate change	+	+ + +	+	-
Profit searching	+	+ + +	+	-

Weather uncertainty (climatic hazards)	+ +	+ + +	+ +	-
Space sharing	+ +	+ + +	+	+
Lightening the work of agriculture	+ +	+ + +	+ +	+
Satisfaction of cultural requirements	-	- -	-	-
Institutional support	+ +	+ + +	+	+

+ + +: very important; + +: intermediately important; +: less important; -: not significant

Table 14: The impacts of scenarios on various issues targeted by the stakeholders

Issues	**Scenario 1**	**Scenario 2**	**Scenario 3**
	Social issues		
Mitigate conflict to land access	-	- - -	+ +
Promote co-existence between farmers and herders	-	- -	+ +
Improve food security	-	+ + +	+ +
Reduction of workload	- -	+ + +	+
Diversification of sources of subsistence	+ +	+ + +	+ +
Reduction of rural exodus	+	+ +	+ + +
Regulate and Comply with the Laws of Gold Mining	+ +	+ +	-
	Economic issues		
Increase in farm income	-	+ + +	+ +
Increase in livestock income	-	+ + +	+
Reduction of expenditures related to the use of chemical fertilizers	+ +	+ +	+

Stimulating economic growth	- -	+ + +	+
	Environmental issues		
Increase soil fertility	- -	- -	+
Reduction of soil degradation	-	- -	+
Extension of the bio-digester	+	+ + +	
Energy subsidy (bottled gas and improved stoves)	+	+ + +	

+ + +: very important; + +: intermediately important; +: less important; -: not significant

4.6. SIMULATIONS

This section is to simulate the scenarios previously identified. For that, the chapter presents how the qualitative description of the scenarios has been translated into quantitative description. After, the results of the simulations are presented and discussed

4.6.1 QUANTIFICATION OF THE SCENARIOS

According to the scenarios, a quantitative value has been assigned to each factor. For that, parameters of the model have been linked to the different factors. Only three factors have been quantified: demography, profit search and space sharing. Demography, profit search and space sharing factors have been linked to growth rate, per capita income, per capita cereal and cotton cultivated area parameters. The values were identified from the literature and from stakeholder’s assumptions (Table 15, Table 16, Table 17 and Table 18). As per capita income, per capita cereal and cotton cultivated area depend on the farmer types, their values have been defined by farm type (Table 16, Table 17 and Table 18). The growth rate in scenario 2 corresponds to the national growth rate while the one in scenario 3 corresponds to the population census in the region of Dano in 1996 .The growth rate in scenario 1 is the growth rate during the population census in 2006 in the region of Dano (INSD/RGPH, 2015).

Table 15: Quantitative values related to the factors of change

Factors	Model parameters	Scenario 1	Scenario 2	Scenario 3
Demography	• Growth rate	1.8	2.4	1.1

Table 16: Quantification of scenarios for small farmers

Parameters	Scenario 1	Scenario 2	Scenario 3
Income per capita (FCFA per capita)	65,000	97,500	65,000
Cultivated area per capita for cereal (ha per capita)	0.225	0.27	0.18
Cultivated area per capita for cotton (ha per capita)	0.3125	0.375	0.25

Table 17: Quantification of scenarios for medium farmers

Parameters	Scenario 1	Scenario 2	Scenario 3
Income per capita (CFA per capita)	100,000	150,000	100,000
Cultivated area per capita for cereal (ha per capita)	0.0625	0.125	0.25
Cultivated area per capita for cotton (ha per capita)	0.4375	0.525	0.35

Table 18: Quantification of scenarios for great farmers

Parameters	Scenario 1	Scenario 2	Scenario 3
Income per capita (CFA per capita)	200,000	300,000	200,000
Cultivated area per capita for cereal (ha per capita)	0.225	0.27	0.18
Cultivated area per capita for cotton (ha per capita)	0.5375	0.645	0.43

4.6.2. The results of simulations

The results of the simulations were used to predict the evolution of population growth, the cereal production by the farmers and their income in the various scenarios. The analysis has been achieved at system level and individual level taking into account the different type's of farmers. As farmers are heterogeneous, assessing the impacts of different scenarios on farmer type's livelihood could allow policy makers to develop adequate policies for different groups of farmers.

4.6.2.1. Population growth and land use change

The population is increasing in the three simulated scenarios (Figure 6). The most important growth is observed in the Scenario 2 having the most important population growth rate followed by the Scenario 1 and Scenario 3. After twenty years of simulation, the population shifted from 1200 to 1800 in scenario 2 while it shifted from 1200 to 1500 in scenario 1 and from 1200 to 1300 in scenario 3.

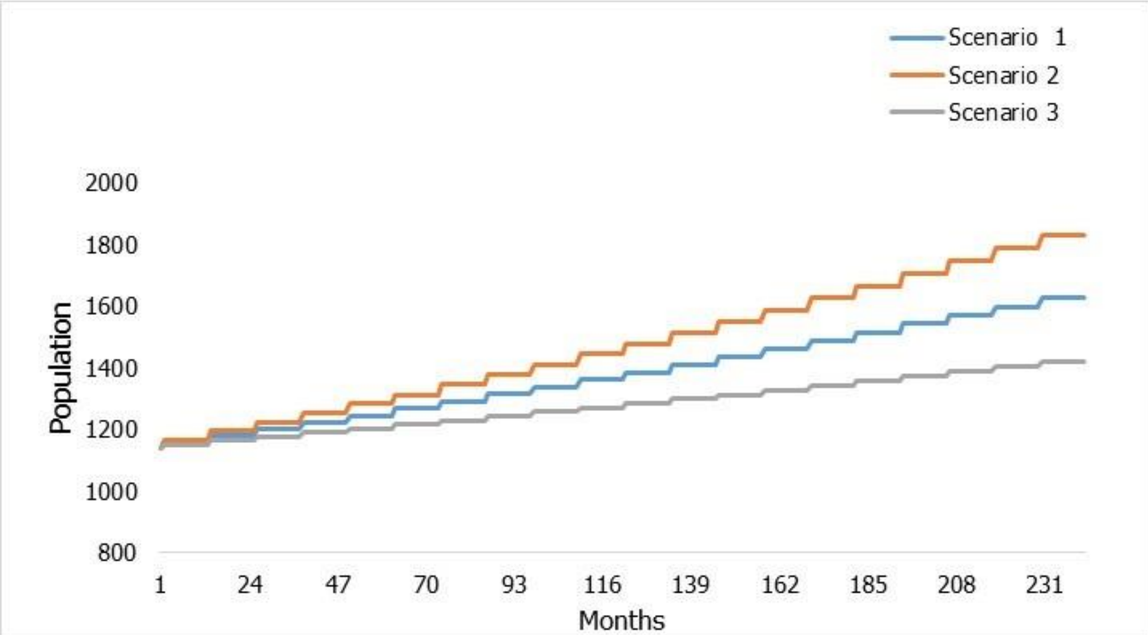

Figure 6: The population growth in different scenarios

As the population is increasing, the land demand for crop production particularly the cereal production is increasing in all scenarios. The land use change differ between scenarios (Table 15).The most important increase is observed in scenario 2 having the most important population growth. Farmers cultivate cereal to meet principally the population food needs. As the population is increasing, farmers increase the cultivated area to meet the food demand which explains why the cultivated area is increasing with the population. The cultivated area per type of farmer can be seen in Annex 3.

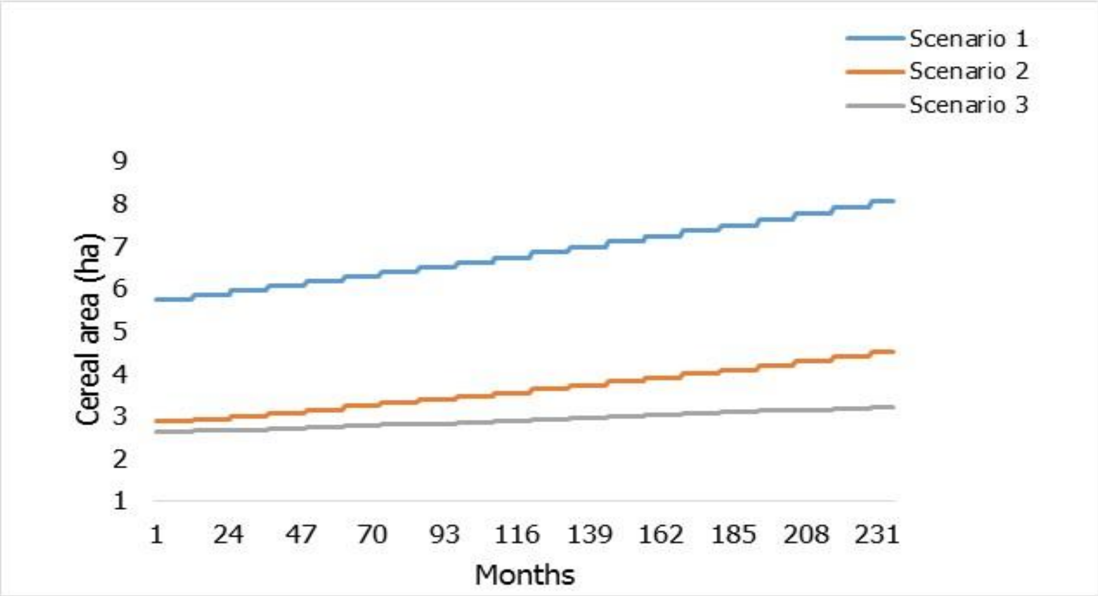

Figure 7: Cereal area cultivated for all scenarios

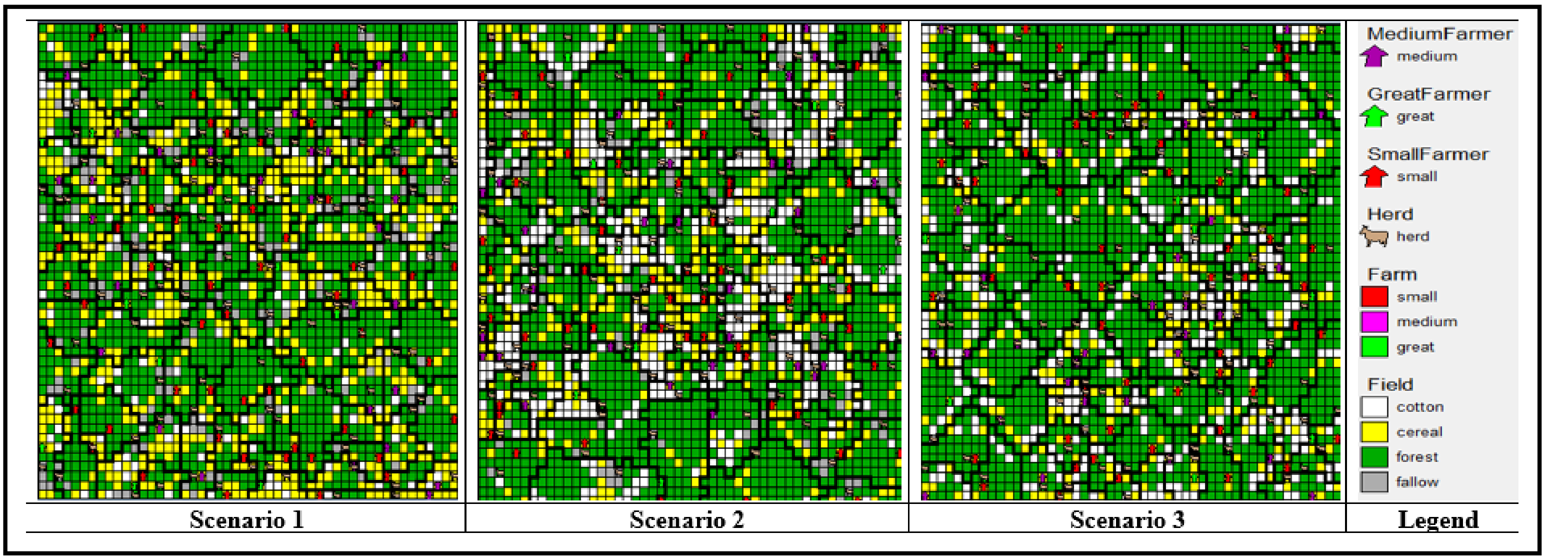

Figure 8: The spatial representation of land use and land cover change in the three scenarios after 20 years of simulation

4.6.2.2. Crop production

Although the increase of the cereal cultivated area, the per capita cereal production is decreasing in all scenarios (Figure 9, Figure 10 and Figure 11), that could be explained by the fact that the population is growing too fast while the available land is limited and the global production does not meet the population food demand. Then, the most important decrease is observed in scenario 2 where the population growth is the most important. The highest per capita cereal production is observed in scenario 1 where the population growth is the lowest. In Scenario 1 the cereal production is evolving between 450 and 500 kg per capita. The analysis of cereal production by farm type showed that the performances of farmer types differ according to the scenarios (Figure 9, Figure 10 and Figure 11). Then, in Scenario 1 the highest production is achieved by the Great Farmers while the highest production in Scenario 2 and Scenario 3 are achieved by the Smaller Farmers and Medium Farmers respectively.

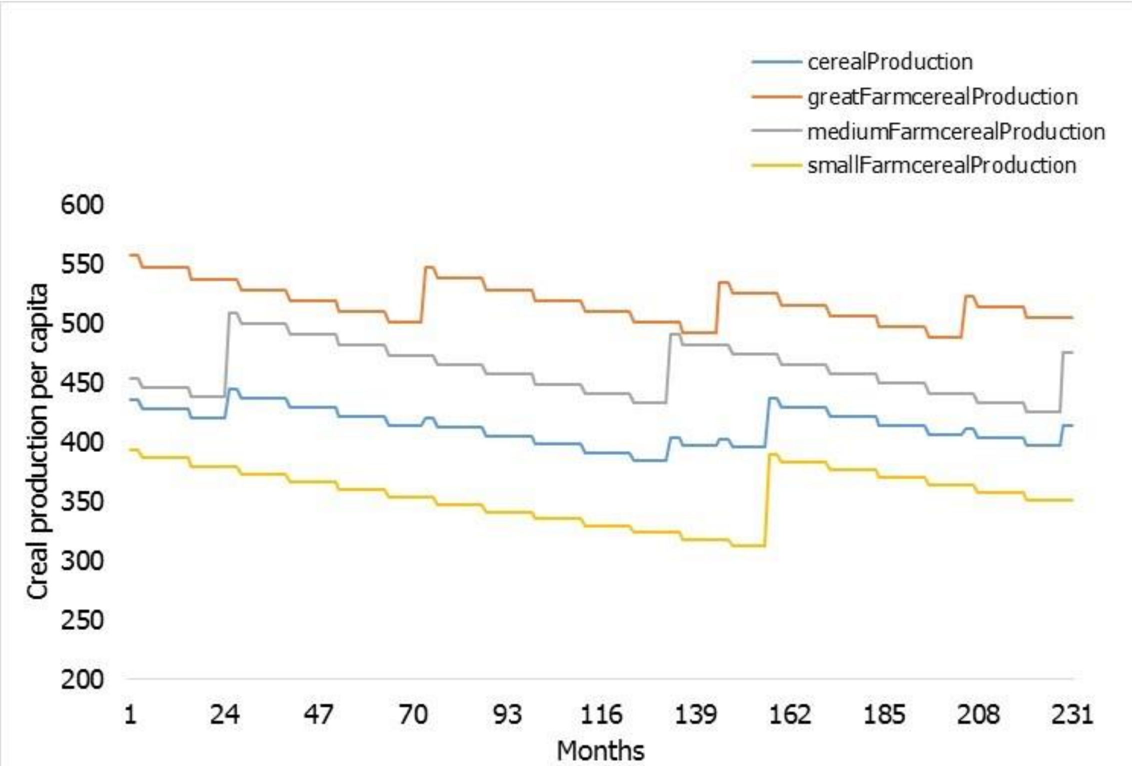

Figure 9: Per capita cereal production in the scenario 1

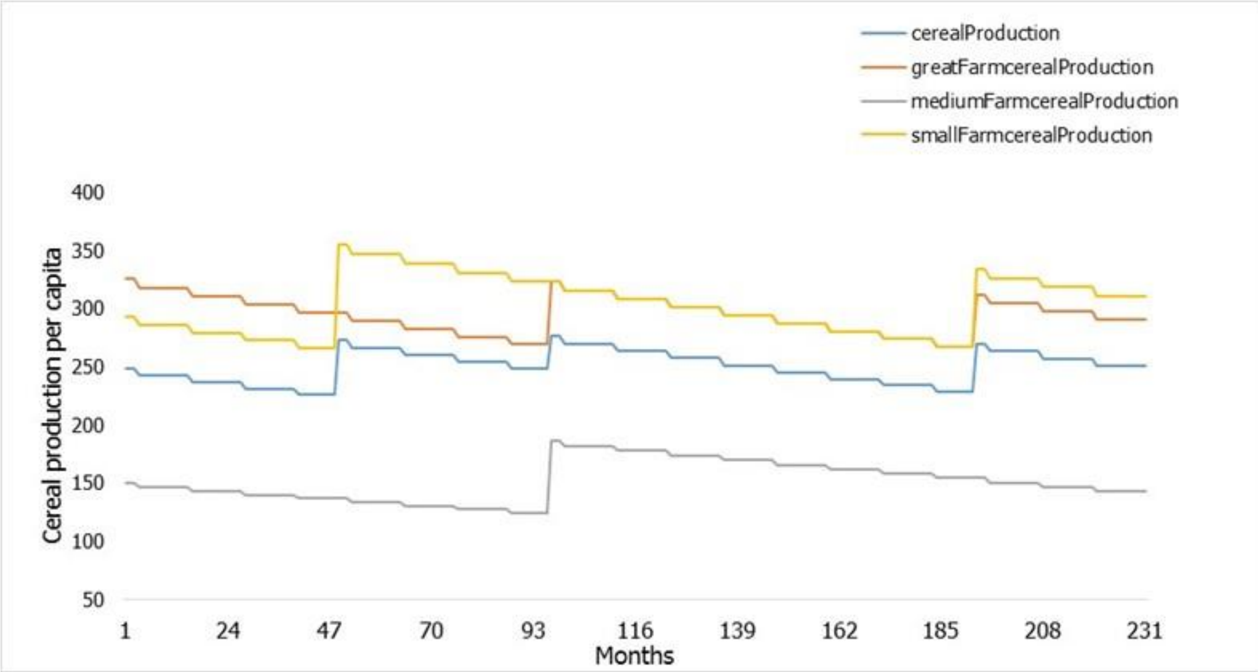

Figure 10: Per capita cereal production in the scenario 2

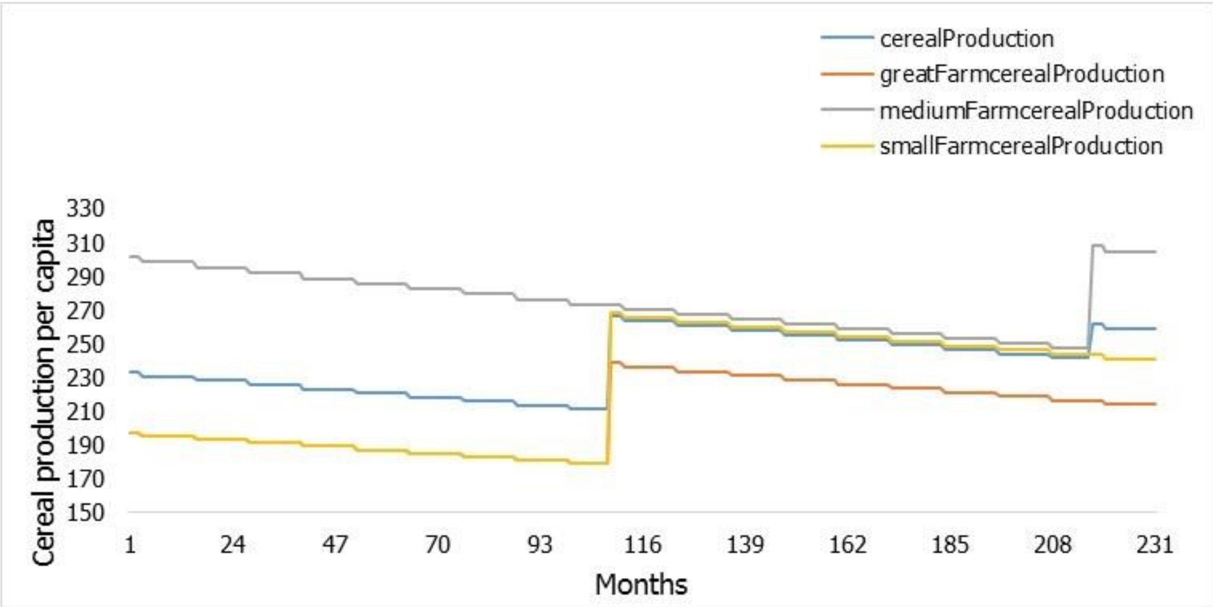

Figure 11: Per capita cereal production in the scenario 3

4.6.2.3. Income for farmers

The most important income is observed in the Scenario 2 followed by the scenario 3 and 1 (Figure 12). The crop intensification in scenario 2 is the highest among the different scenarios followed by the scenario 3 and scenario 1. Then, the high crop intensification allows a higher crop production and consequently income generation from crop production. The income according to the type of farmers can be seen in Annex 3.

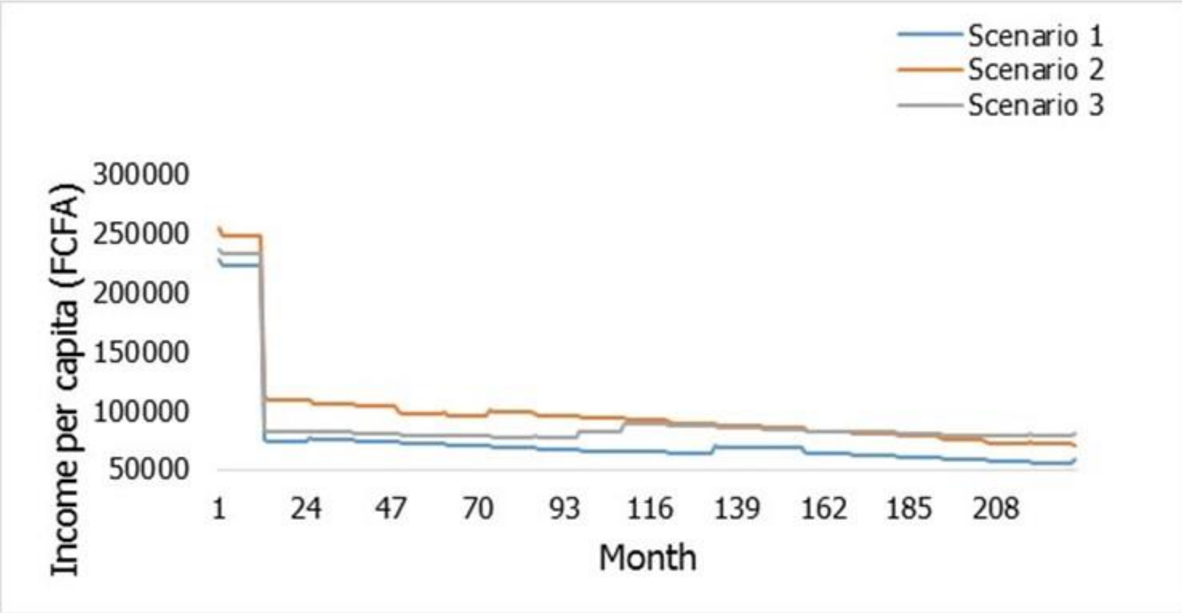

Figure 12: Per capita income in the three scenarios

4.7. CONCLUSION

This chapter allowed to achieve the process of stakeholders' engagement in the study. Then, the main actors of crop-livestock integration have been identified and mapped. The main issues of the various stakeholders were identified and scored. In order to develop alternative scenarios for crop-livestock integration, the main factors of changes were identified and assessed. Finally, four scenarios for the crop-livestock for the 20 next years were identified and described. The description of the different scenarios showed how the different factors evolved in the various scenarios and how the different scenarios impact the stakeholders' issues. All of that allowed to have a common understanding of the crop-livestock system in the study. Then, based on the stakeholders' points of view and the identified scenarios, we can now develop the agent-based model to target the stakeholders' issues and scenarios. The next chapter presents the discussion, conclusion and provides recommendations.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

5.1. DISCUSSION

5.1.1. MODELING FOR KNOWLEDGE INTEGRATION

The main stakeholders and issues in crop-livestock integration found in Dano have been identified by Meda (2016). But some issues have been added by the participants during the workshop which include on compliance with the laws of gold mining, extension of the bio-digester and the subsidization of the energy.

Four scenarios have been identified but the fourth scenario does not reflect reality because we all know that demography cannot decrease and there is null crop-livestock integration.

This study combined participatory approach and ABM which was used to simulate the impacts of crop-livestock in various socio-economic aspects in different climate configurations. The results allowed the assessment of the impacts of crop-livestock integration both at the system level and the individual level.

The approaches used showed the relevance of participatory approach and modeling in knowledge integration from different sources and to assess the impacts of policies. The crop-livestock system involves various stakeholders. These various stakeholders may not necessarily have the same points of view on the target problem. Their points of view are complementary or opposite. That calls to develop a relevant framework in integrating the different points of view and to have a common understanding of the target problem. Participatory approach and modeling are relevant to that. As the participatory approach allows to integrate knowledge from social and pure scientists, modeling allows to link the different knowledge and to provide a basic representation of the complex system.

In this study, the participatory approach was used to provide a common understanding of the crop-livestock system through the development of a conceptual model and a set of scenarios to design together the future context of the crop-livestock system that take into account the main issues from the various stakeholders. Table 14 shows how the identified scenarios contribute to achieve the different issues identified by the stakeholders. Based on that, the stakeholders can identify the sustainable scenarios to formulate adequate policies that meet their perspectives.

As the modeling, it is used to integrate the different points of view and to assess how the different scenarios impact in the future the crop-livestock integration and farmers' livelihood. In addition, the modeling approach allowed to quantify the scenarios and link the different factors to the model parameters. As some parameters are dependent on farm types, my approach allowed to link the factors of change to crop-livestock outcomes as farm types are viewed as outcome.

Voinov et al. (2016) identified seven components of participatory modeling (Table 19). In this current study, the stakeholders have been involved in the study delimitation, the development of the conceptual model and the scenarios formulations. The stakeholders involved in this study concerned the researchers, policy makers, farmers and other institutions. However, the model has been developed by the modelers and evaluated by the scientists.

Table 19: Involvement of the stakeholders in the modeling process.

PM component	Stakeholders engagement
Scoping & abstraction:	The objective of the modelling process has been identified with the scientists. The study has been delimitated by the stakeholders.
Envisioning & goal-setting	The stakeholders have developed the conceptual model using the ARDI approach.
Model Formulation	Modelers have developed the model. But the scenarios and the related factors have been identified by the stakeholders.
Collection of original data and cross-checking of expert data	The data have been collected by the scientists, completed through interview of stakeholders, previous works and expert knowledge.
Apply Model to decision-making	The model is not applied in other case of study
Evaluation of outputs	The output has been evaluated by the stakeholders and through literature review and expert knowledge

5.2. CONCLUSION

The objective of this study is to co-develop with stakeholders innovative scenarios for crop-livestock integration in Dano watershed. Specifically, the study sought to develop with the stakeholders a conceptual model on crop-livestock integration, innovative scenarios and an agent-based model for the simulation of the scenarios. This study is based on the assumption that a better understanding of the environmental problems requires integration of scientific and local population knowledge.

The method used was based on participatory approach combined with the agent-based model. With the stakeholders, a conceptual model has been developed. After, four scenarios have been identified and described by the stakeholders. The four scenarios are based on different contexts of crop intensification, institutional support and crop-livestock integration. **Scenario 1** represents a context of very high institutional support and low crop intensification low crop-livestock integration. **Scenario 2** is a context of very high crop-livestock integration, high institutional support and high crop intensification. **Scenario 3** is a weak crop-livestock integration with a high crop intensification and low institutional support. Finally, **Scenario 4** is a context with no crop-livestock integration. Based on the identified scenarios, an agent-based model is developed to integrate the various points of view from the stakeholders and to simulate their decision making in the different scenarios.

The results showed the relevance of participatory and modeling approaches to understand and to tackle the complex environmental problem. This approach allows to extract and integrate knowledge from different sources for a better understanding of the target problem. In addition, it provides a relevant framework to formulate and assess the impacts of policies in short and long terms. As policies formulation and implementation are difficult and expensive, using modeling approach allows an ex-ante analysis of these policies and to reduce the cost of policies formulations and implementation.

As further works, this approach will be applied at a larger scale to assess the articulations between local and global scenarios. In addition, a relevant stakeholder’s framework will be developed for policy formulations for crop-livestock integration at large scale. Finally, the approach will be improved by associating the role playing games.

5.3. RECOMMENDATIONS FOR CROP-LIVESTOCK IMPROVEMENT

Based on the results and the discussion with the stakeholders, the following recommendations that could contribute to the improving the crop-livestock integration in the context of climate change are made:

1. Diversification of farmers' activities that could improve the farmers' income. The income generated from extra activities could be invested in crop production and consequently improve food production.
2. Improving the institutional support to farmers and human resources management institutions. The improvement of institutional supports will facilitate the access to subsidies, credits, input and the infrastructure development. Reinforcement of institutions in human capacities will improve the technical supports to farmers and consequently the crop-livestock integration.
3. Modernize the livestock production. The modernization of livestock production would improve the animal production and the interactions with the crop production and face resources scarcity due to climate change. In addition, that could contribute to the energy production through the bio-gas technologies.
4. Improve the access to local, regional and international markets. The access to markets is one of important issues in Dano region. Improving access to the market access would increase the willingness of farmers to produce cash crops, to increase their production and consequently to improve their income.
5. Secure land access. Land access insecurity hampers the crop, animal production and it is a source of conflicts in Dano region. Then, securing land access could contribute to improve the crop-livestock integration in Dano.

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Annex 1: **WORKSHOP TO CO-CONSTRUCT A MODEL TO EXPLORE FUTURE SCENARIOS OF CROP- LIVESTOCK INTEGRATION (CLI) IN DANO**

FROM 12 TO 13 OCTOBER 2017 IN DANO

Context

In the context of climate change, scarcity of resources, reduced crop yields and increased product prices, crop-livestock integration is increasingly becoming an adaptation strategy in south-western Burkina Faso. Crop-livestock integration contributes to the management of fertility, the reduction of land degradation, the increase of farmers' income and the increase of crop yields.

However, today, many challenges have emerged that require rethinking crop-livestock integration. Indeed, in the context of climate change, population growth, pressure on the resources on which agriculture and livestock depend has increased, leading to increased competition with other activities. In addition, climate change and the socio-economic context have led to a significant change in the roles played by agriculture-livestock integration in south-western Burkina Faso. Initially practiced for cultural reasons, agricultural-livestock integration practices are now used as strategies for adaptation to climate change, income generation and improving the resilience of the population to climate change. In addition, new technologies have been developed that enable efficient nutrient recycling and energy production and, consequently, enhance the contribution of crop-livestock integration to improving the livelihoods of the local population. Finally, the institutional context of the agriculture-livestock system is evolving with new actors playing new roles that need to be taken into account for effective integration between agriculture and livestock.

The objective of this workshop is to co-build with the actors a conceptual model and develop future scenarios for the improvement of agriculture-livestock integration in Dano.

This workshop will bring together for two days officials from the Ministry of Agriculture and Water Resources, the Ministry of Animal and Fisheries Resources and the Ministry of the Environment, Green Economy and Climate Change, agents, NGOs and producers.

Specific objectives

- Identify and analyse interactions between actors and resources / products in the agriculture and livestock sectors
- Build a conceptual model that shares the views of different actors
- Develop future scenarios for improving agriculture-livestock integration

Expected results

- The different actors and resources are known
- A conceptual model sharing the different points of view is developed
- Future scenarios are developed.

Premium and support

The participants of this workshop will receive 10.000F CFA per day per participant during the two (02) days. Coffee breaks and lunch will be taken care of during the two (02) days.

Location: UPPCB (Cotton-Bio) meeting room

Duration of the workshop: 2 days

Program of the workshop

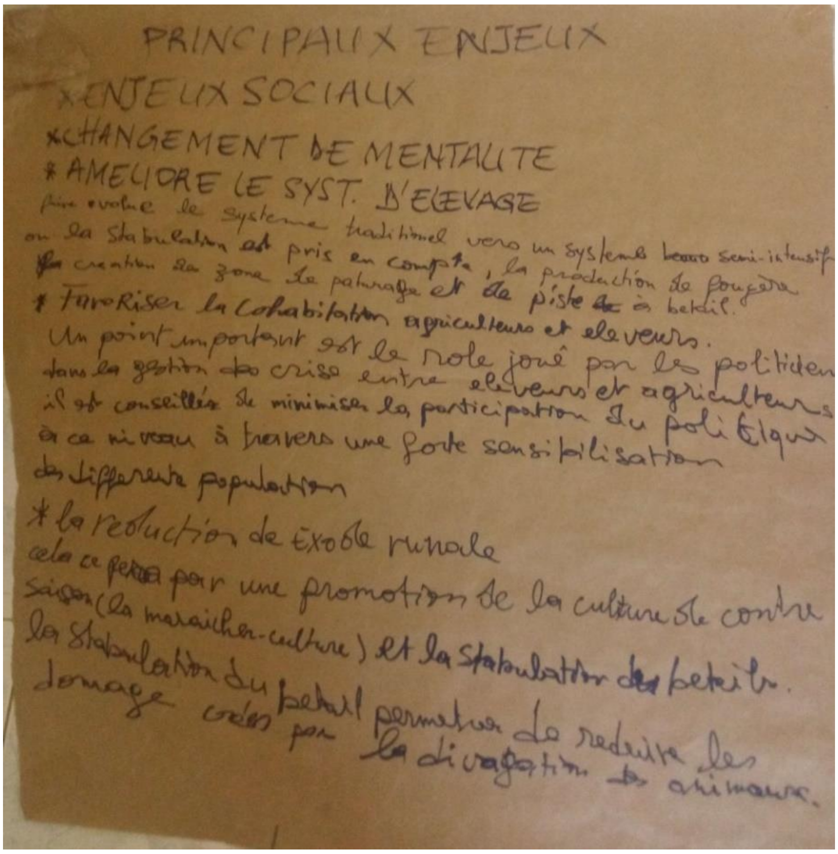
Date/Schedule	Activities	Responsible
Day 1 : 10/12/2017		
8h-8h30 am	Presentation of the group / Presentation of the objectives of the workshop and the program	
8h30-10h am	Identification of the collective issue / Identification of actors in the field of study and resources	
10h-10h30 am	coffee break	
10h30-12h pm	Identification of the dynamics of the system: (dynamic: social- economic-biophysical and political)	
12h-1h pm	Lunch	
1h-2h pm	Description of interaction diagram between actors	
2h-3h pm	Description of the global interaction diagram	
3h-4h pm	Identification of spatial and temporal scales (actors)	
4h-5h pm	Identification of relevant indicators among the actors / resources	
Day 2 : 10/13/2017		
8h-8h30 am	Identification of relevant indicators among the actors / resources	
8h30-10h am	Consensus on identifying actors / resources indicators	
10h-10h30 am	Coffee break	
10h30-12h pm	Identification of past factors influencing the evolution of crop-livestock integration	
12h-1h pm	Lunch	
1h-2h pm	Identification of future factors that will impact the evolution of agriculture-livestock integration.	
2h-3h pm	Assessment of certain and uncertain factors over time	
3h-4h pm	Scenario development from the two most uncertain factors	
4h-5h pm	Evaluation of the workshop by the participants.	

Thank you for your participation.

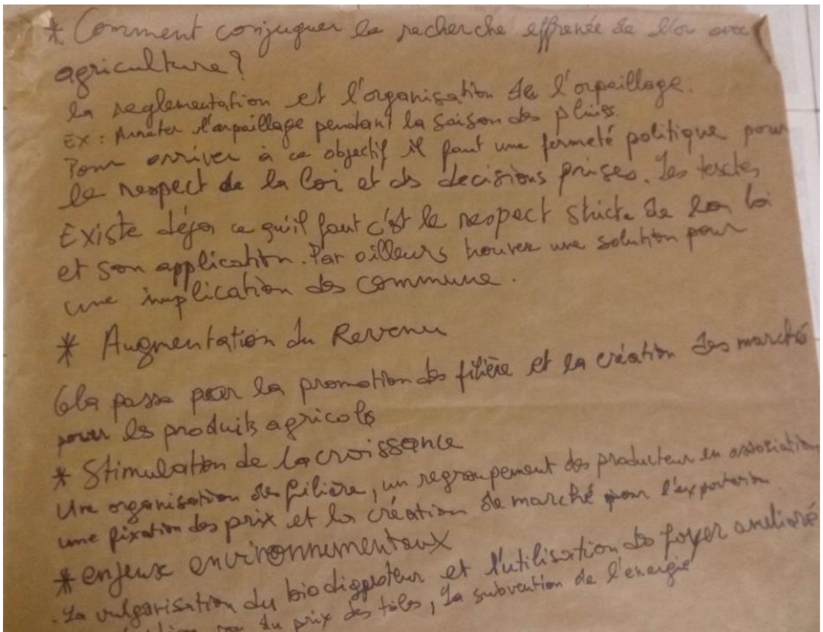
Conclusion

At the end of this workshop we will be able to identify the different stakeholders which intervene on the field. Also, the resources on the field are identified and the different linkages which exist between them and the actors. Likewise, the indicators and dynamism are known. Scenario are developed through factors which influence crop-livestock integration in the past even in the future.

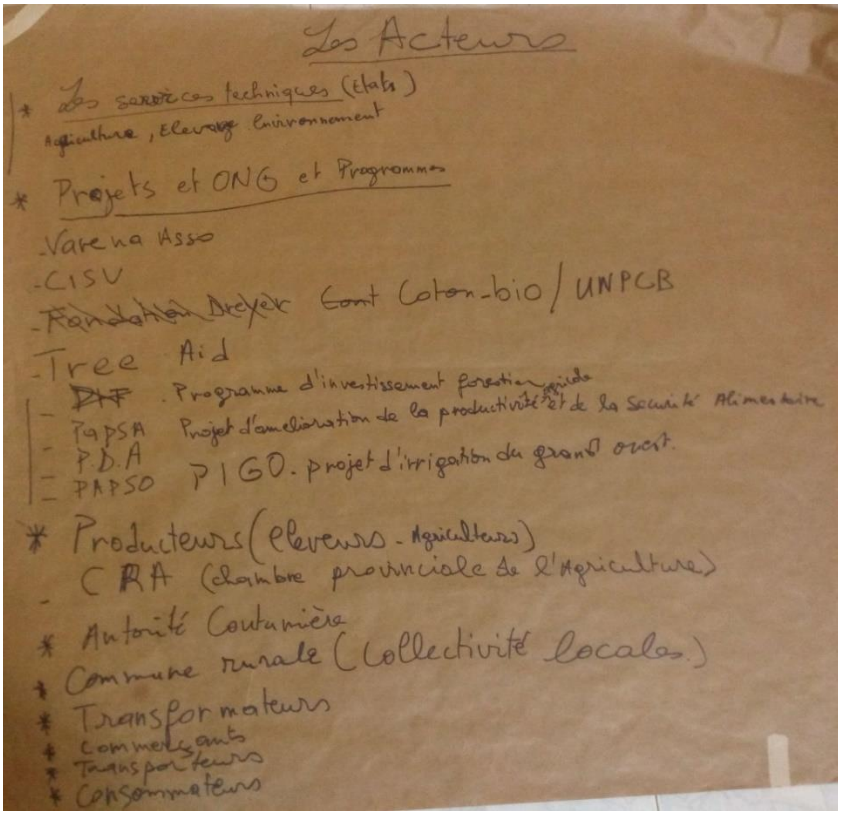
Annex 2: **DIFFERENT STEPS OF THE WORKSHOP**



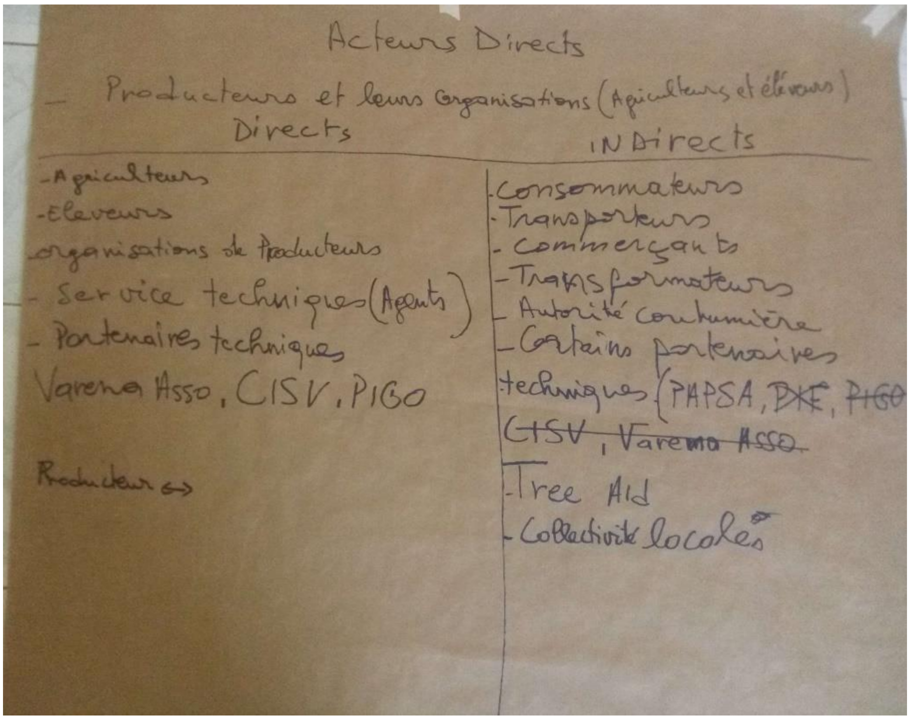
Annex 2; Figure 1: Main issues of farmers in Dano's municipality



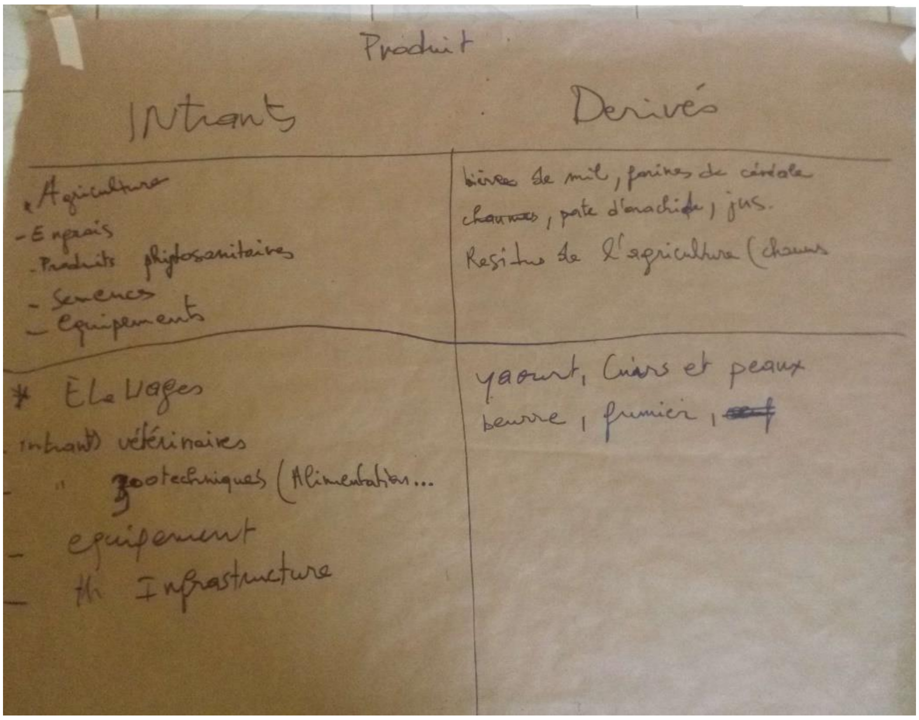
Annex 2; Figure 2: Main issues of farmers rest in Dano's municipality



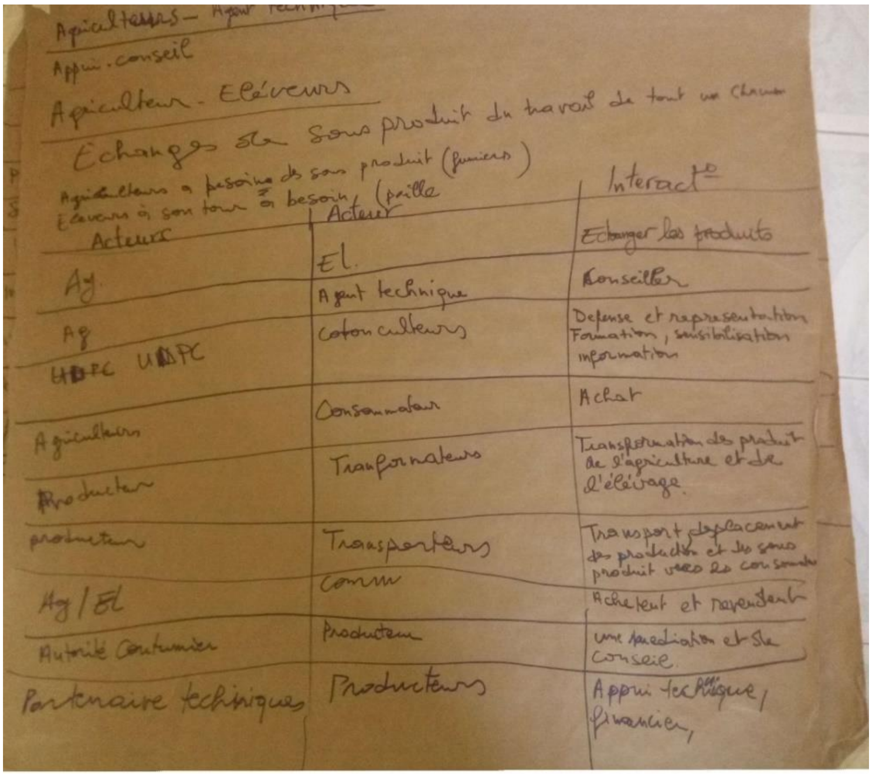
Annex 2; Figure 3: Main actors in Dano's municipality



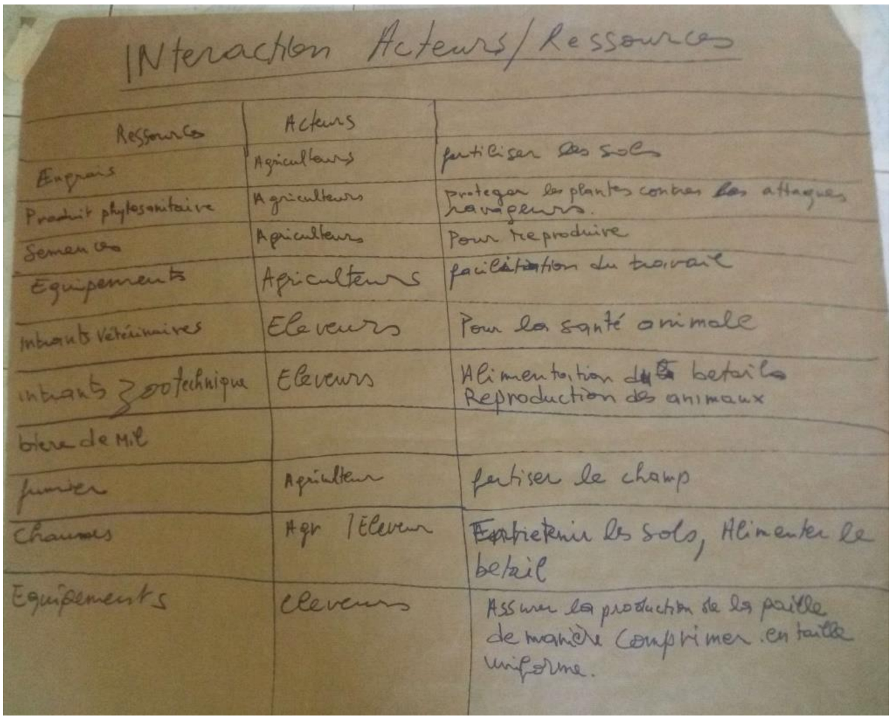
Annex 2; Figure 4: Direct actors in Dano's municipality



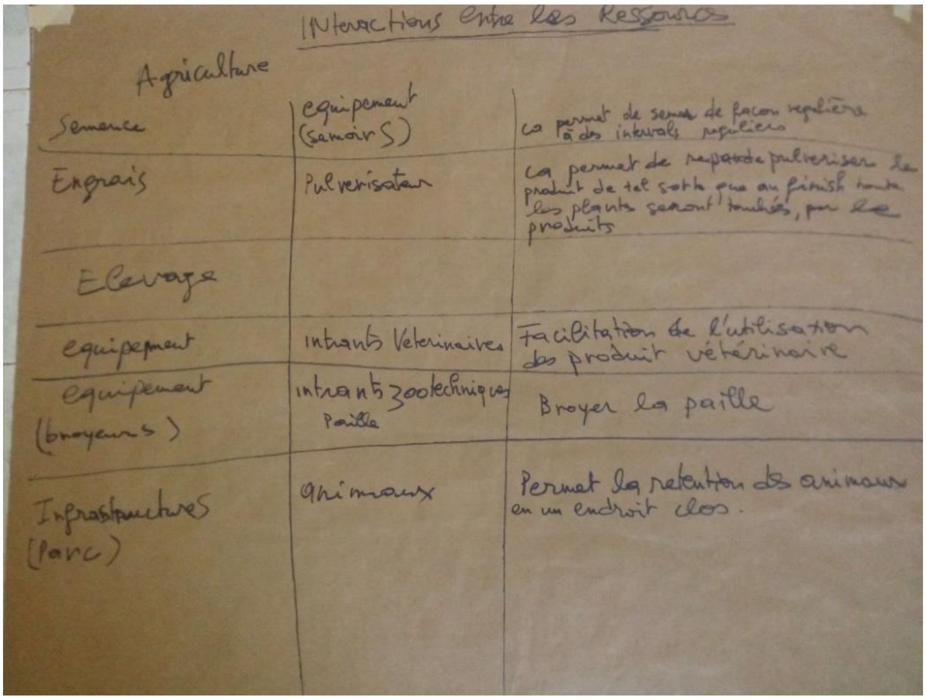
Annex 2; Figure 5: Resources in Dano's municipality



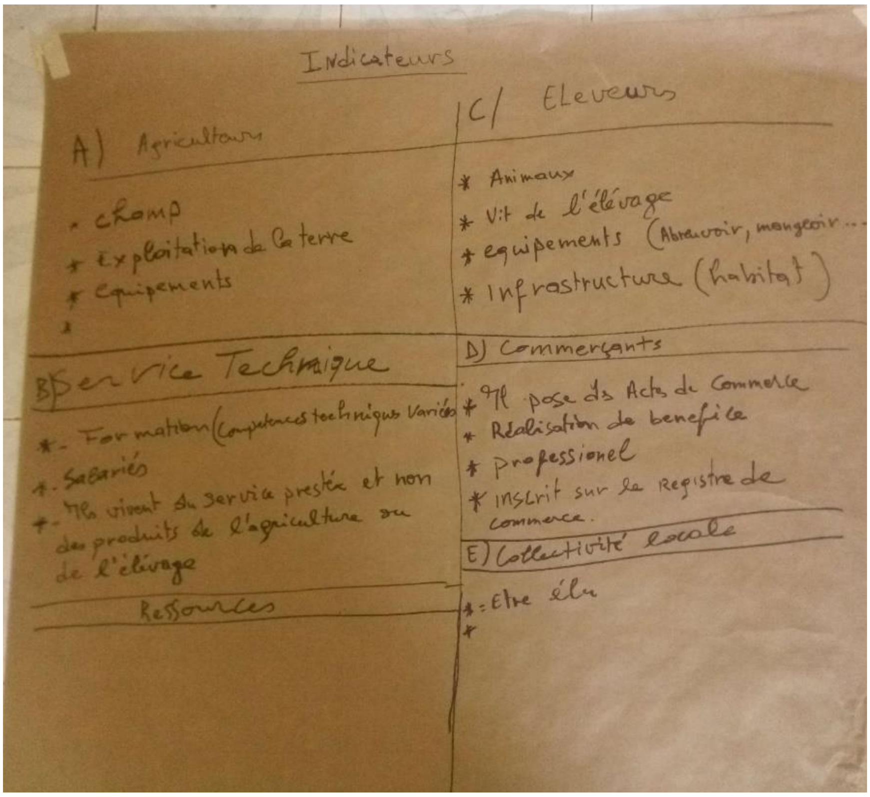
Annex 2; Figure 6: Interaction between actors



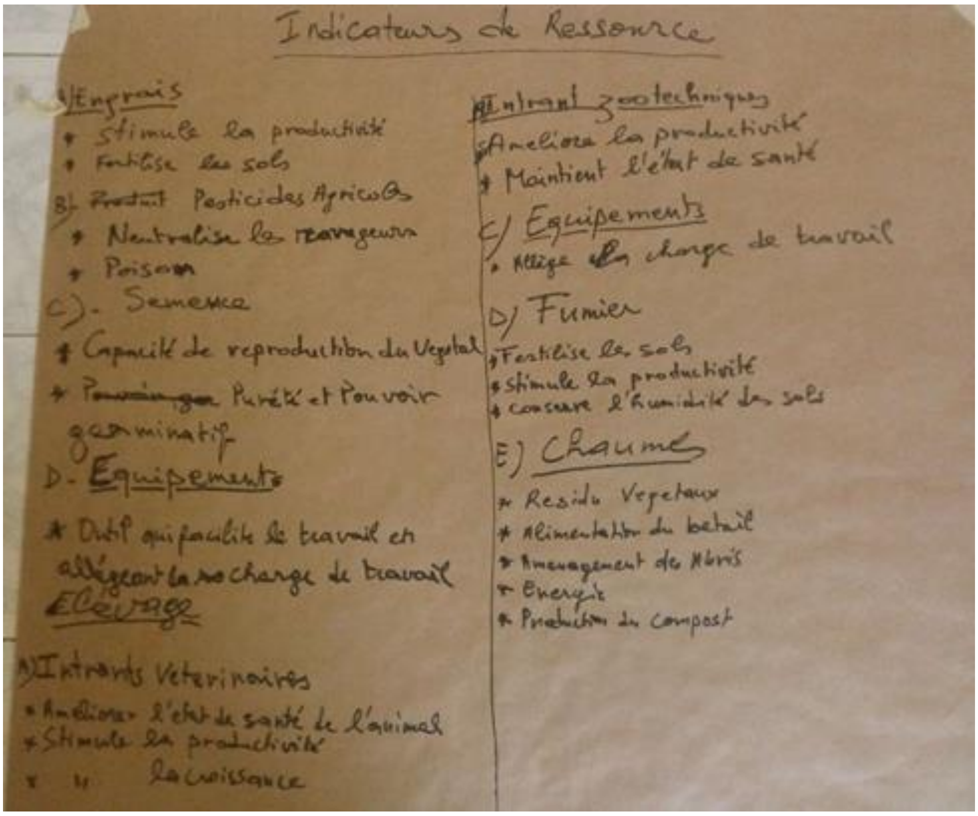
Annex 2; Figure 7: Interaction between resources



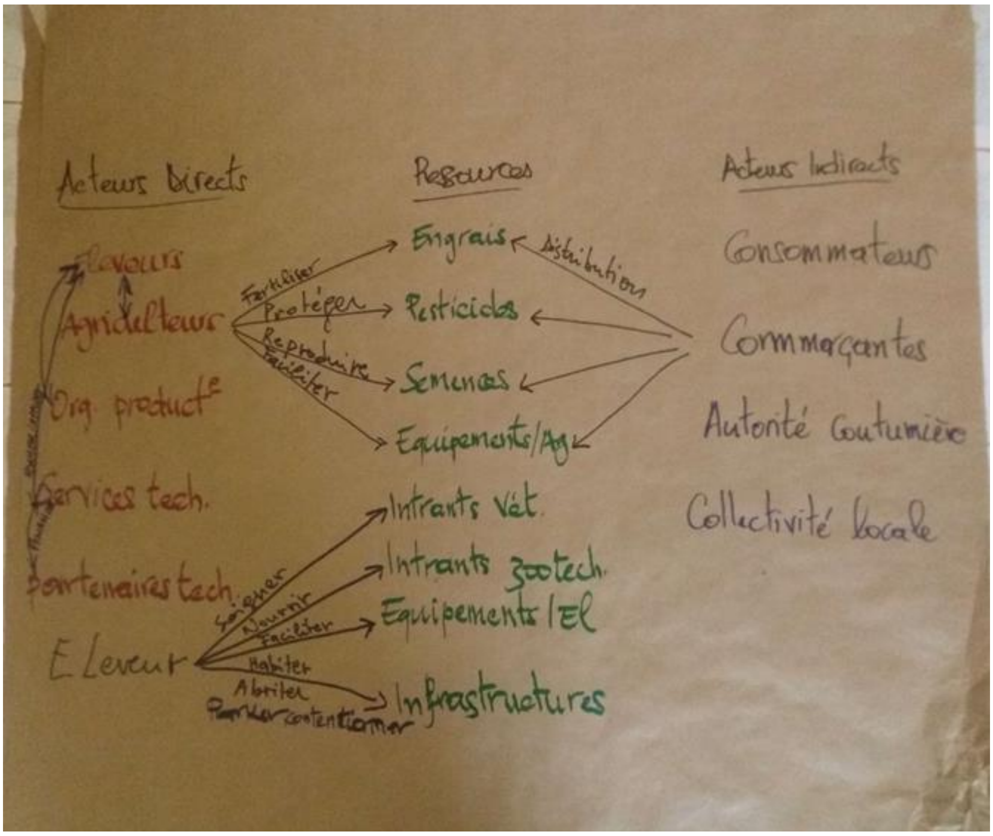
Annex 2; Figure 8: Interaction between resources rest



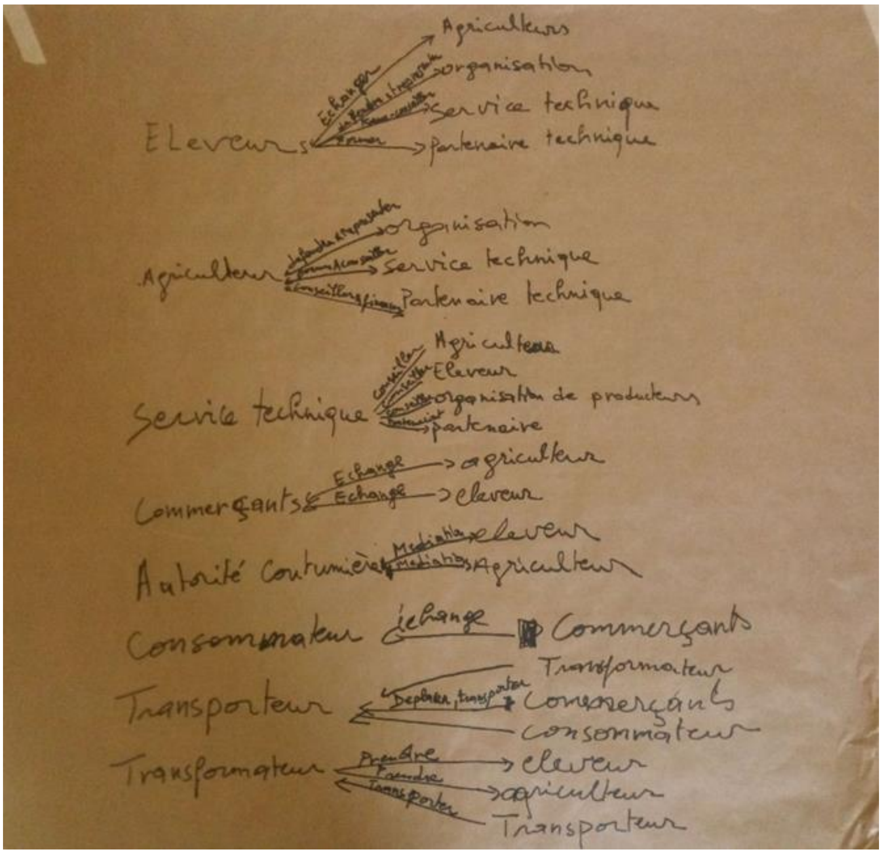
Annex 2; Figure 9: Indicators of actors



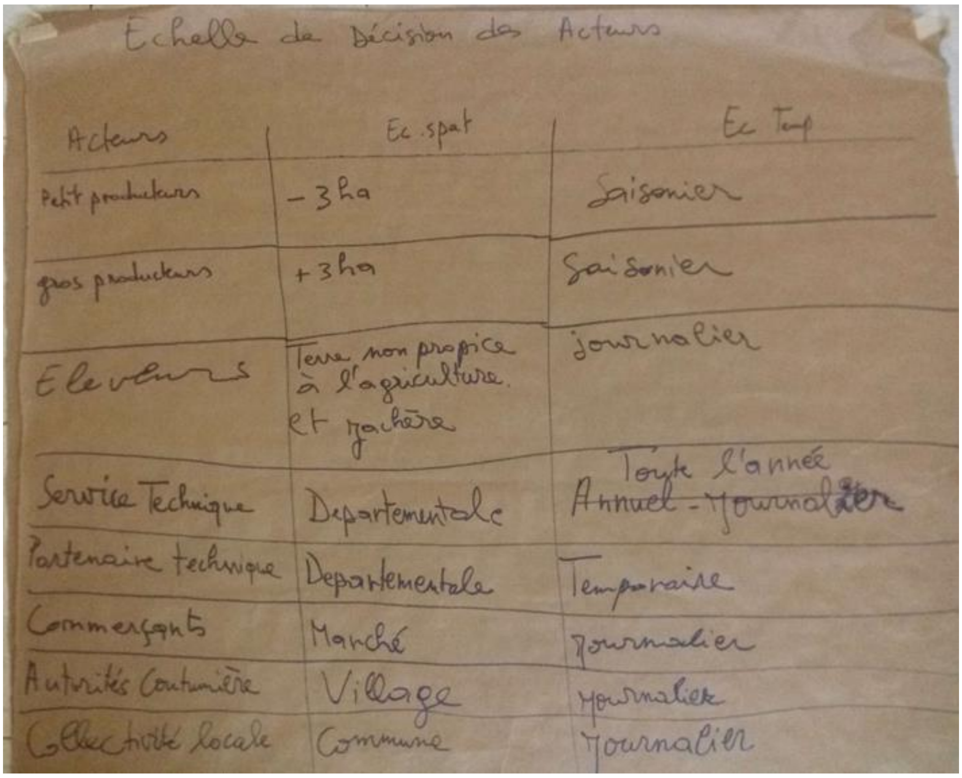
Annex 2; Figure 10: Indicators of resources



Annex 2; Figure 11: Dynamics between actors and resources



Annex 2; Figure 12: Dynamics between actors and resources rest

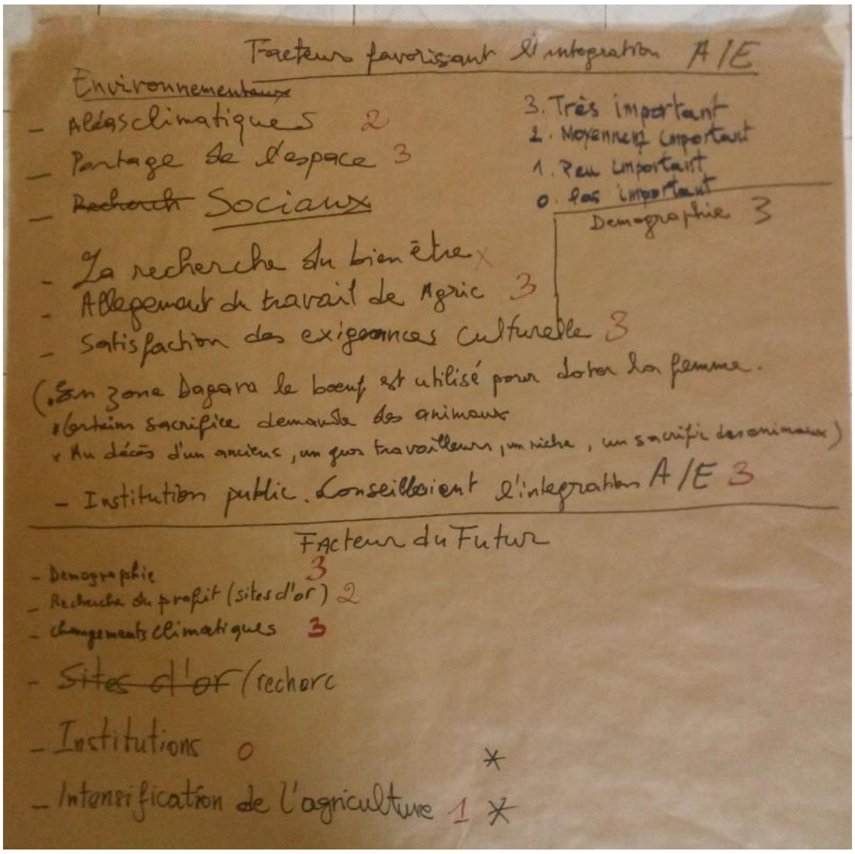


Echelle de Décision des Acteurs

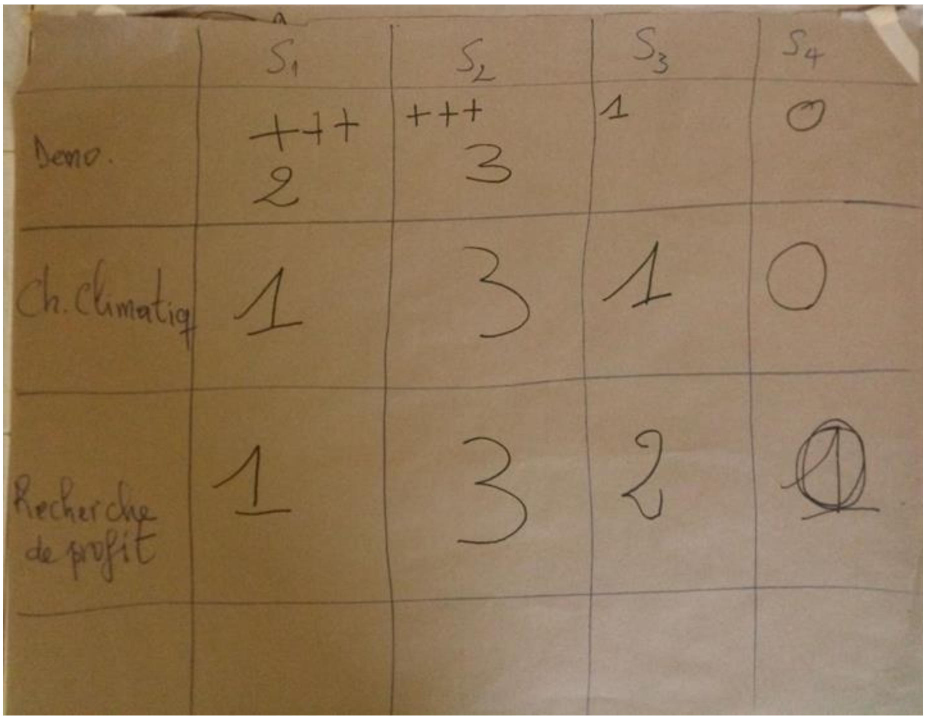
Acteurs	Ec. spat	Ec Temp
Petit producteurs	-3 ha	Saisonier
gros producteurs	+3 ha	Saisonier
Eleveurs	Terre non propice à l'agriculture. et jachère	journalier
Service Technique	Departementale	Toute l'année ~~Annuel - Journalier~~
Partenaire technique	Departementale	Temporaire
Commerçants	Marché	Journalier
Autorités Coutumière	Village	Journalier
Collectivité locale	Commune	Journalier

Annex 2; Figure 13: Decision scale of stakeholders

Annex 2; Figure 14: Scenarios development



Annex 2; Figure 15: Scoring of factors intervening on crop-livestock integration

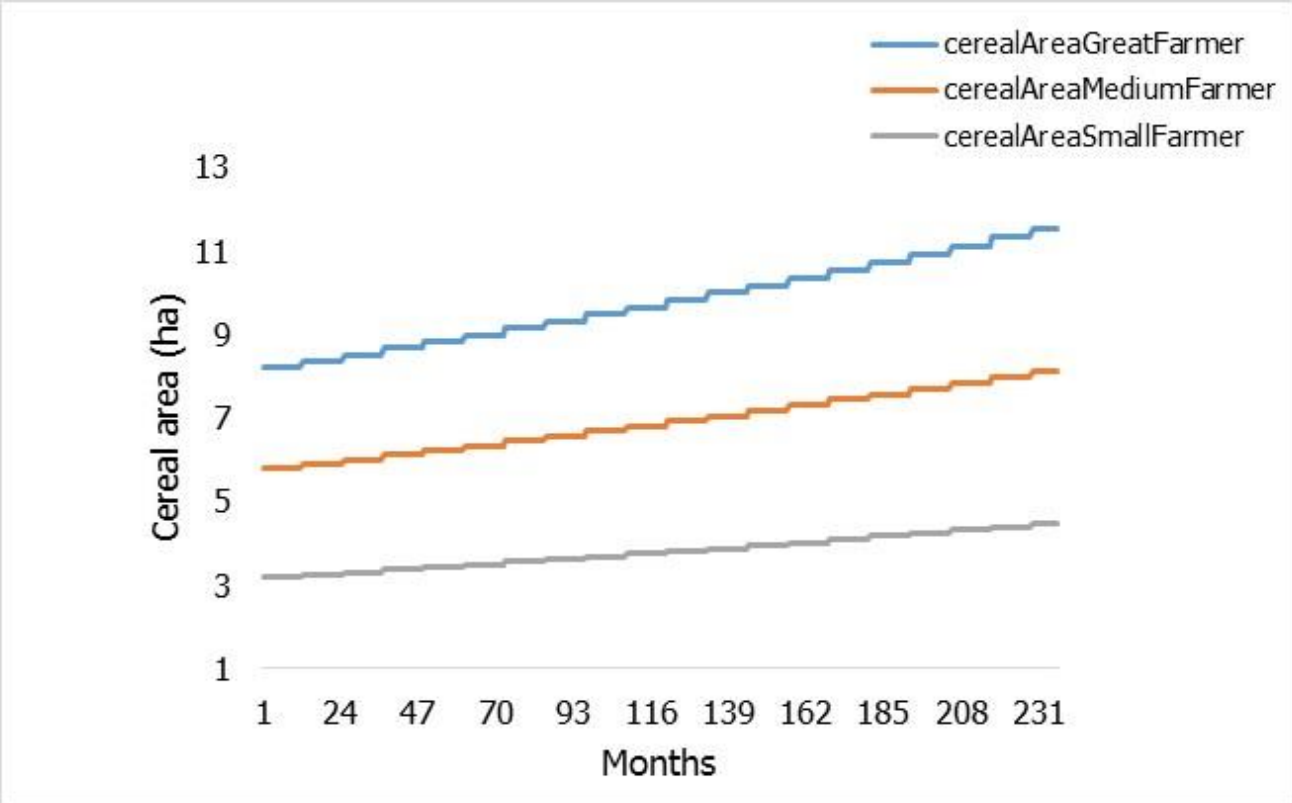


Annex 2; Figure 16: Scoring of factors evolving in the four scenarios

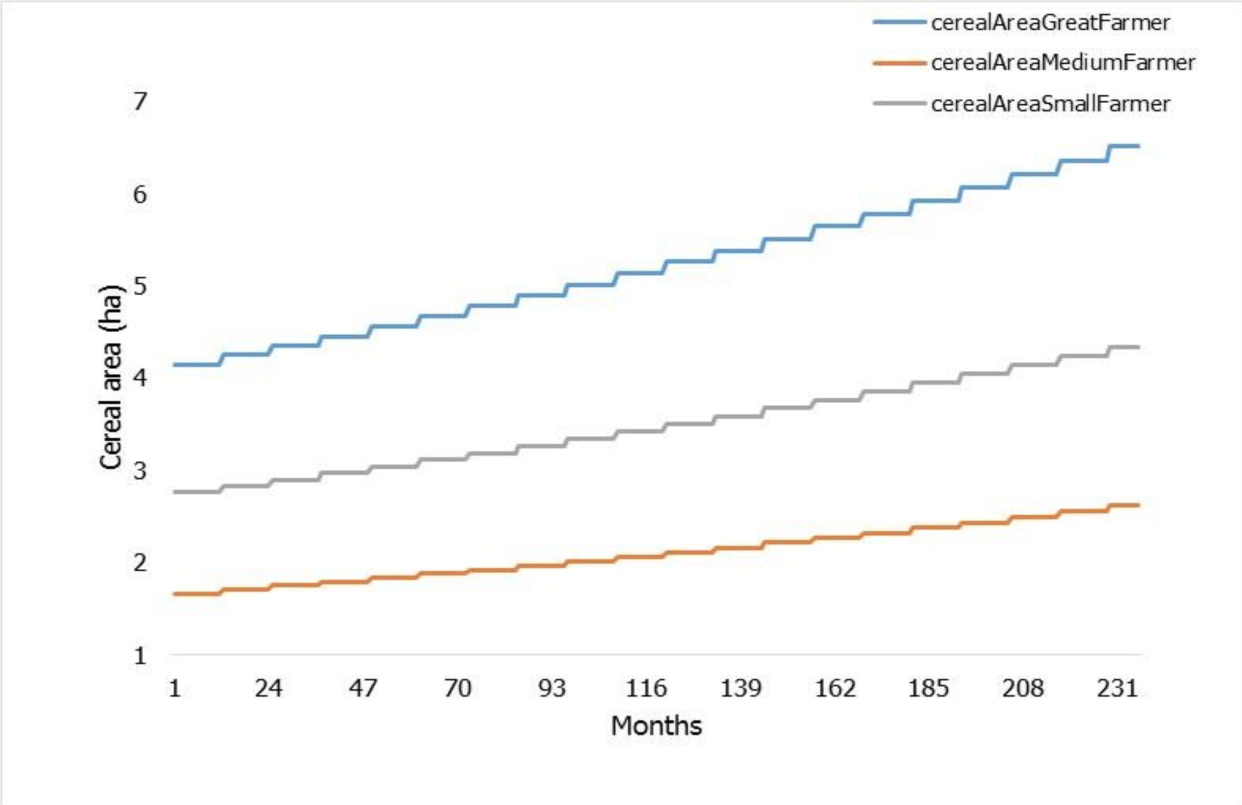
Annex 2; Photo 1: Reflection of participants

Annex 2; Photo 2: Participants sharing their point of view

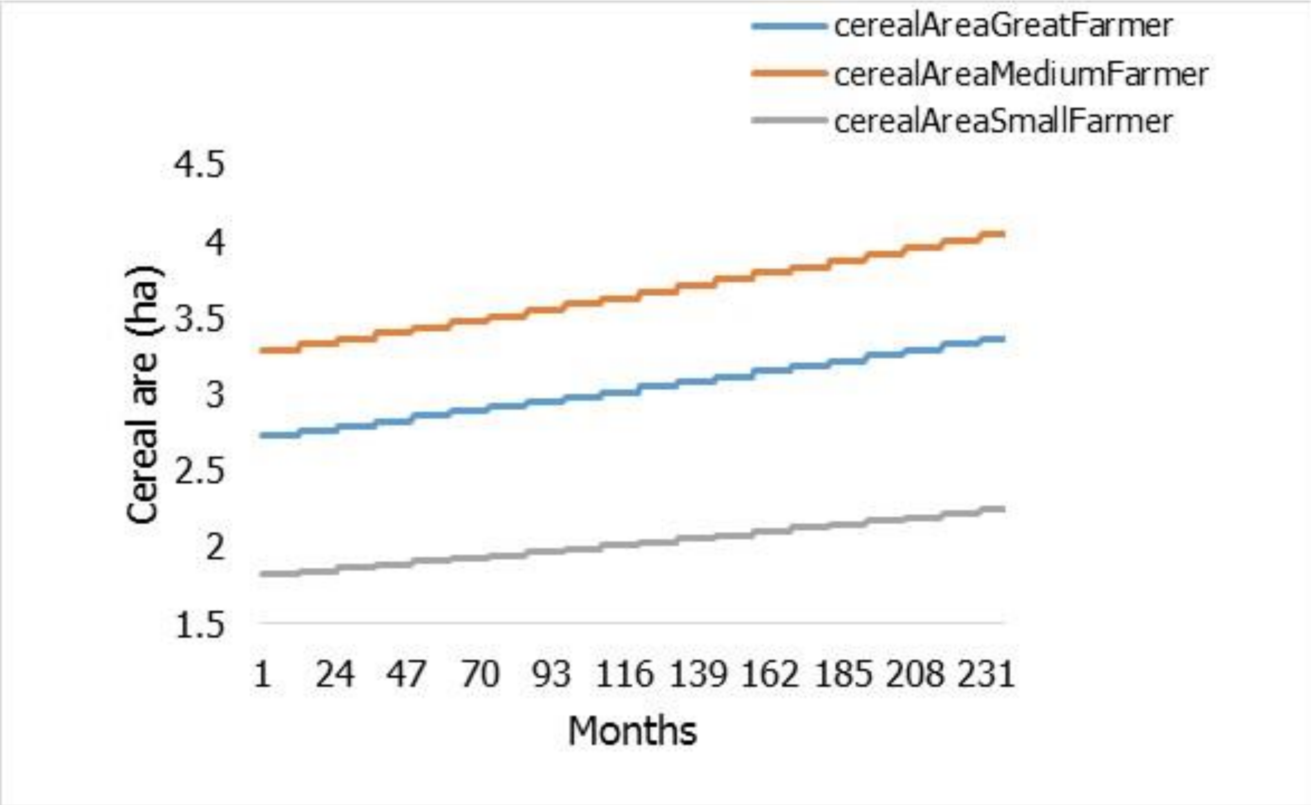
ANNEX 3: CEREAL AREA AND INCOME FOR ALL THE THREE SCENARIOS



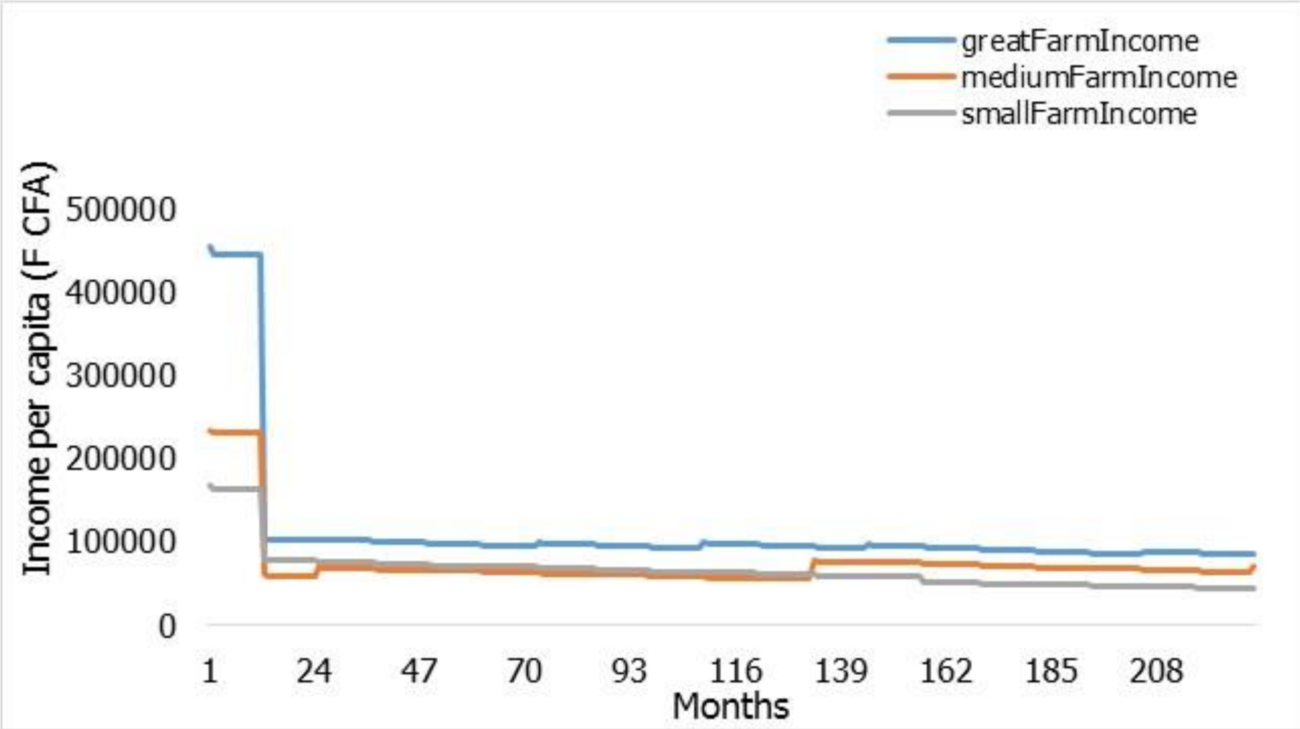
Annex 3; Figure 1: Cereal area by type of farmer in the scenario 1



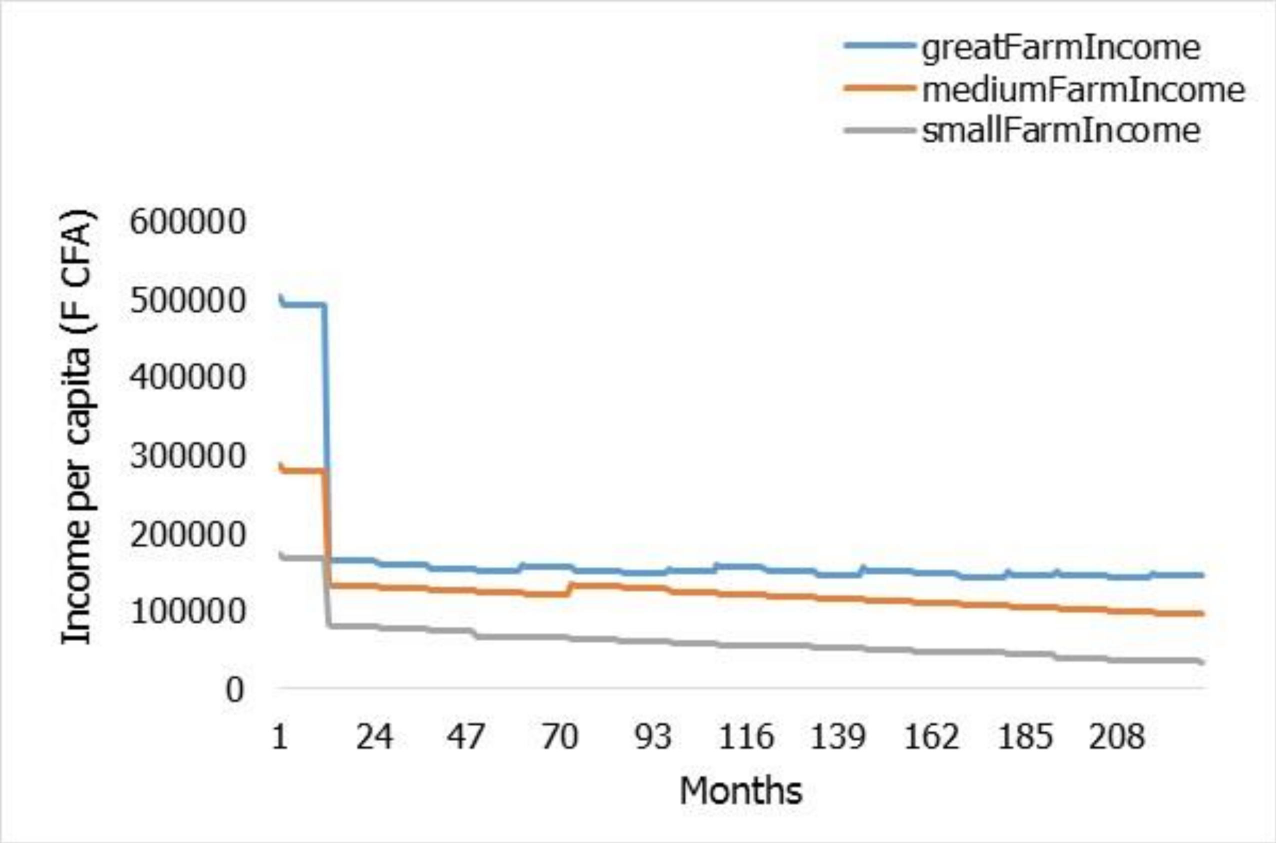
Annex 3; Figure 2: Cereal area by type of farmer in the scenario 2



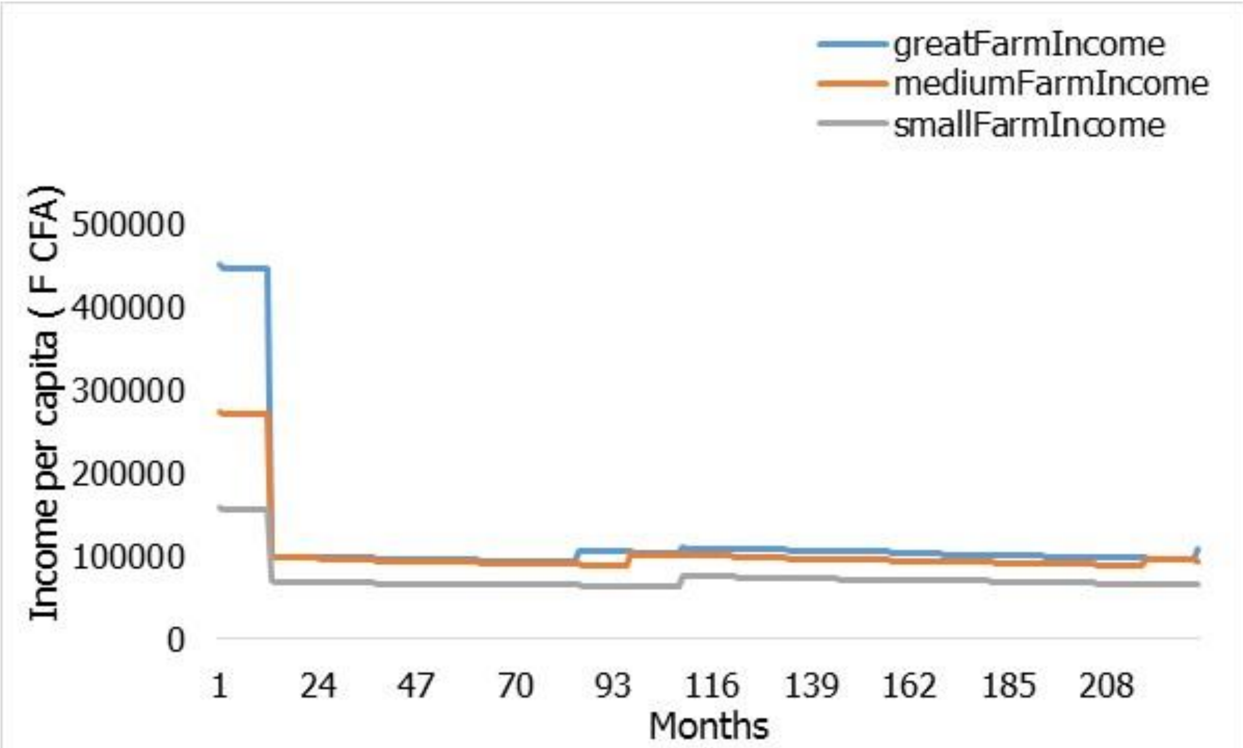
Annex 3; Figure 3: Cereal area by type of farmer in the scenario 3



Annex 3; Figure 4: Per capita income by type of farmer in the scenario 1



Annex 3; Figure 5: Per capita income by type of farmer in the scenario 2



Annex 3; Figure 6: Per capita income by type of farmer in the scenario 3