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TERROIRS COMPARISON IN TERMS OF BIOMASS FLOWS AND NITROGEN BALANCE

Study case of Diohine and Barry Sine in the former groundnut basin

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TERROIRS COMPARISON IN TERMS OF BIOMASS FLOWS AND NITROGEN BALANCES- STUDY CASE OF DIOHINE AND BARRY SINE IN THE FORMER GROUNDNUT BASSIN

Key-words : visible nitrogen balance, biomass flows, fertility, multi-scale, participative workshop, Sereer country

Mots clés: bilan apparent d'azote, flux de biomasse, fertilité, pluri-échelle, atelier participative, pays Sereer

Résumé:

Le vieux bassin arachidier du Sénégal s'inscrit dans un contexte de changements du milieu physique, politico-social et économique qui a résulté en une forte compétition d'usage des ressources naturelles et donc en une transition agraire déconnectant les secteurs d'agriculture et d'élevage.

Deux terroirs furent étudiés, l'un ayant un modèle traditionnel qui conserve la jachère commune (Diohine), l'autre ayant adopté la pratique d'embouche (Barry Sine). Des bilans de nutriments pluri-échelle à dire d'acteurs furent indicateurs de la durabilité des options qu'ils ont choisies et un atelier participatif capta leurs perceptions et dynamiques gestion de la fertilité par terroir et par genre.

Les bilans azotés à l'échelle des parcelles sont négatifs dans les deux terroirs mais supérieur dans le cas de Diohine (-13 $kgN.ha^{-1}$ contre -24$kgN.ha^{-1}$ à Barry Sine) ainsi que l'efficience azotée (116 contre 4 à Barry Sine). En revanche à l'échelle du ménage comme à l'échelle du terroir, les bilans azotés sont positifs et Barry Sine présente des résultats supérieurs (24kgN/ha^{-1} contre 11 à l'échelle du ménage, 25$kgN.ha^{-1}$ contre 9$kgN.ha^{-1}$ à l'échelle du terroir).

L’efficience azotée à l’échelle du ménage est supérieure à Diohine (1.11 contre 0.92) mais inférieure à l’échelle du terroir (0.12 contre 0.64).

Finalement, les outils d’amélioration de la fertilité des sols diffèrent par terroir et par genre avec des préférences par spécialisation agricole. Les voies d’améliorations sont concentrées sur l’intensification de pratiques existantes et sur l’aide extérieure mais des innovations et des financements internes sont envisagés.

Abstract:

Physical, socio-political and economical changes impacted the former Senegalese groundnut basin what resulted in a strong natural resources use competition and therefore an agrarian transition that disconnects cropping and livestock farming sectors.

Two terroirs were studied, one within a traditional model that conserved common fallows (Diohine), the other one that adopted livestock fattening practice (Barry Sine). Multi-scale nutrient balances based on surveys were sustainability indicators for the selected options and a participative workshop gathered their fertility management perceptions and dynamic *per* terroir and *per* gender.

Plot scale nitrogen balances are both negative but higher for Diohine (-13 kgN.ha^{-1} for -24kgN.ha^{-1} in Barry Sine) as well as nitrogen efficiency (116 for 4 à Barry Sine). On the other hand household and terroir scale nitrogen balances are positive and Barry Sine presents higher results (24kgN/ha^{-1} for 11 at household scale, 25kgN.ha^{-1} for 9kgN.ha^{-1} at terroir scale). Household nitrogen efficiency is higher in Diohine (1.11 for 0.92) but lower at terroir scale (0.12 for 0.64).

Finally, soils fertility improvement tools described are different according to the terroir and genders with preferences *per* agricultural specialisation. Improvements are mainly based on existing practices intensification and on external funds but innovations and internal funding are considered.

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List of abbreviation, acronyms, charts and illustrations

CIRAD : French Agricultural Research Centre for International Development

CGIAR : Consultative Group on International Agricultural Research

DM : Dry Matter

ECO&SOLS: Functional Ecology and Biogeochemistry of soils and Agro-ecosystems

ES: Environment and Societies

FU: Feed Unit

[g]: see the definition in the glossary

GDP : Growth Domestic Product

IFPRI : International Food Policy Research Institute

INRA : French National Institute for Agricultural Research

IRD : Institute of Research for Development

ISRA : Senegalese Institute for Agricultural Research

JRU: Joint Research Unit

KBBE: European Knowledge- Based Bio-Economy

LEMSAT : Laboratory of Microbial Ecology of the Agro Eco Tropical Systems

LU : Labour Unit

NAP : New Agricultural Policy

PPZS : Dry Zone Pastoral Pole

RM : Raw matter

SELMET : Mediterranean and Tropical Livestock System

TTA : Total Terroir Area

TLU : Tropical Livestock Unit

UAL : Utilised Agricultural Land

Introduction

Agricultural sector in Senegal gather about 60% of the Senegalese labour force by itself (Ngom 2006). Nevertheless the country does not meet its population food needs and large amounts of foodstuff are imported (FAO 2010). Moreover, the « Global Hunger Index » calculated by the IFPRI (International Food Policy Research Institute) qualify Senegal's position as « serious» counting about 17% of undernourished between 2005 and 2007 (Von Grebmer et al. 2011). Poverty is affecting more than half its population including 34% living with less than 1$ per day. Rural environment is particularly impacted and tend to maintain this tendency (FAO 2010), indeed, agriculture is only 14% of the GDP (Growth Domestic Product) in Senegal (Ngom 2006).

Facing population growth and rural exodus (Courtin and Guengant 2011) majors national issues are food security and improving rural living conditions in particular (CIRAD 2013). In Western Africa, (except the Sahelian zone), agrosylvopastoral systems are predominant (Ngom 2006, CIRAD 2013). In the studied area, the “former Senegalese groundnut basin”, the traditional agricultural system is based on millet and cattle complementarity (Lericollais 1999).

Nonetheless, a gradual disconnection between cropping and livestock farming has been observed in the major part of the terroirs[g] (Delaunay and Lalou 2012). This agrarian transition results from global and local environmental changes such as climate change, population growth and land pressure (Vandermeersch et al. 2013) that led to a continuous reduction of herds' range and therefore extending transhumance length. The increasing price of mineral fertilizers makes manure even more essential to compensate for these nutrient flows outside of the terroirs to renew soils fertility and maintain crop yields

As life quality for Sereer's ethnic group principally depends on the crop-livestock interaction, research must focus on agrarian system ecological intensification considering local environment in a poverty context (Vandermeersch et al. 2013).

Many scientific projects about ecological intensification technologies have already been developed but have not been adopted by local people (FAO 2003). It is therefore essential to base theses changes on actors willingness (Wezel and Rath 2002).

The main goal of this study is to compare two villages which adopted very contrasted agricultural strategies in Niakhar's zone in terms of practices, biomass flows organization, nutrient balances and local dynamics perceived through interviews and participative workshop. One of them conserved a traditional system with fallow while the other one developed livestock fattening[g] to face local social, economical and environmental evolutions. We will tend to explain the functioning and sustainability differences by perception, resources management collective rules and individual strategies dissimilarities adopting a systemic approach.

First the context of the study will place this analysis in the frame of the activities and projects the organization, the CIRAD. Then, the adaptations of the terroirs will be highlighted by the socioeconomical and environmental context to understand the interest of this comparison. The description of the methodology used will map out the concept and tools used and the reason why we selected them. Finally the results obtained will compare villages, their agricultural systems, the nutrient balance and stakeholders' perceptions and options proposed to improve their soils fertility and enhance their yields.

PART 1 : Introduction

1 The study framework

1.1 The CIRAD

The CIRAD (French Agricultural Research Centre for International Development) is a public enterprise of industrial and commercial nature status. It is established in more than 90 countries and gathers 1800 agents including 800 researchers. Its purposes and goals consist in producing and transmit new knowledge for agricultural development in Southern countries what leads it to participate in present and future agricultural issues debates. Its research activities are developed around four poles: food security, poverty, inequities and natural resources management.

The study was part of the Environment and Societies (ES) scientific department which has a special focus on social dynamics (CIRAD 2009a), the joint research unit SELMET (Mediterranean and Tropical Livestock System) consisting in answering food needs and global agricultural issues through livestock ecological intensification (CIRAD 2012a) and the Dry Zone Pastoral Pole (PPZS) based in Dakar aiming at improving pastoral resources management, economical performances and producers living conditions (CIRAD 2012b).

KBBE (European Knowledge- Based Bio-Economy) AnimalChange European project (An Integration of Mitigation and Adaptation Options for Sustainable Livestock Production under Climate Change), which is funding this study, aims at studying relationships between livestock farming and climate change considering a range of different scales. Its second goal is to create models and tools to help a more sustainable livestock farming development (Animal Change 2011).

1.2 Intervention sites: upper Casamance, groundnut basin and Ferlo

Agricultural systems diversity and the Senegalese ecological gradient cover motivated the CIRAD JRU SELMET’s intervention sites choice. The first studied zone is located in the Sudanian climate zone near Kolda, the following ones (described in this document) are in the Sudano-Sahelian climatic zone between Fatick and Diourbel. Finally, a third similar study is currently taking place in the Ferlo, in the Sahelian climatic zone (see figure 1).

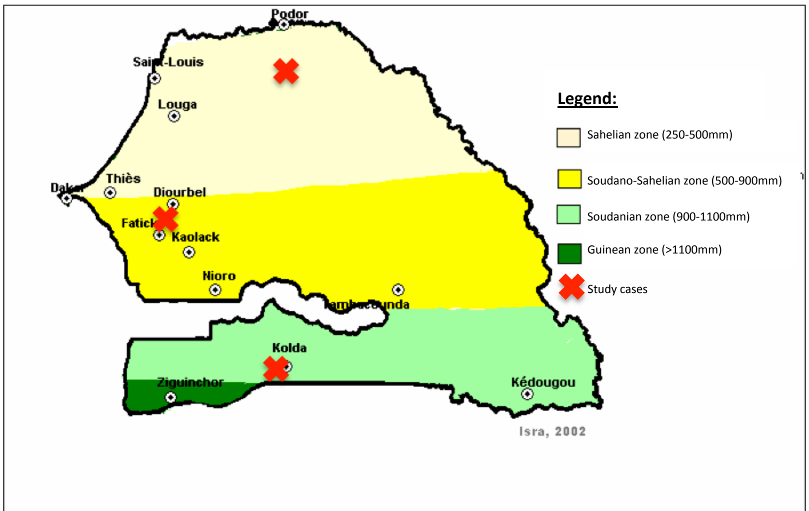


Figure 1: Localisation of the 3 principals intervention sites of CIRAD JRU SELMET in relation to the climate zoning

Source : adapted from Cisse and Hall 2002

In addition to climatic diversity, intervention sites diverge from agricultural practices point of view. Kolda conserved a particularly traditional agricultural system based on fertility transfer from rangeland to crops through herds (Manlay 2001). By contrast, the second intervention site near Fatick and Diourbel is closer to the capital Dakar and Thiès and was therefore subjected to a stronger and faster agricultural transition characterized by progressive mobile and extensive herd disappearance and, in some terroirs, an intensive trough-fed livestock system with limited mobility development. Finally, the third intervention area, the Ferlo is defined by an agricultural system specialised in pastoral livestock farming given its particularly harsh climatic conditions.

The second and third areas are complementary for livestock activities. They function as source and sink model in terms of animal flows, Ferlo being a reproduction and birth favoured area and the groundnut basin being a fattening area to provide large towns market in meat. Furthermore, transhumant[g] herds annual track seasonally varies between Ferlo and the groundnut basin.

2 Livestock fattening development in the former groundnut basin

Socio-economical, environmental and economical context of the second CIRAD's studied area (the former groundnut basin) will voluntarily focus on the reason that enhanced agricultural transition and especially livestock fattening.

2.1 Environmental reasons

2.1.1 Environmental pressure raise and cropping system impacts

Niakhar IRD's station is the older health and demographic surveillance centre of Africa. It was established in 1962 and has been monitoring demographic evolutions and studying societal and agricultural changes (IRD 2013). In 1961, Senegal took a census of 3 millions of inhabitants, in 1984, the population already doubled reaching 6 millions of inhabitants. Lericollais A., Sereer culture and groundnut basin specialist for more than 30 years, estimated in the 90's that the terroir was already saturated but Senegalese population was about to exceed 8 millions in 2000. Indeed, currently, Senegalese are 9.3 millions (FAO 2013) with about 6 children per woman on average (Delaunay and Lalou 2012). One hand, Dakar captured part of the population growth, but on another hand, rural population and the studied area in particular adhered to the national trend moving from 100 inhabitants/km^2 in 1963 to 200 inhabitants/km^2 in 2009 (see figure 2) (Courtin and Guengant 2011) that is to say doubling the demographic pressure in a 40 years interval (Delaunay and Lalou 2012).

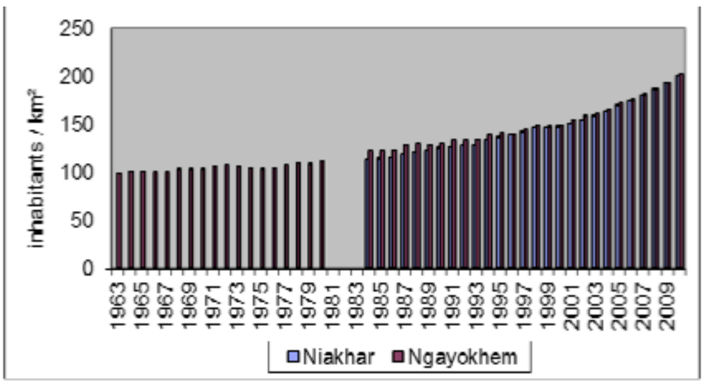


Figure 2: Population density evolution in Ngayokhem and Niakhar area between 1963 and 2009

Source : Delaunay and Lalou 2012

The demographic pressure rise leads to cropping area extension to meet food requirements. Indeed only *dior*[g] and *deck-dior*[g] soils were cropped traditionally as they are less dense than *deck*[g] soils while nowadays the last one is cropped too (Jouve 2001, Reiff and Gros 2004). Because of terroir saturation, cropping extension was also reflected by forest and fallows area drop (Becker 1984, Lericollais 1999, Jouve 2001, Reiff and Gros 2004, Badiane, 2006, Delaunay and Lalou 2012, Lalou and Grémont 2012).

2.1.2 An intense competition between human and livestock needs

The former groundnut basin has one of the highest livestock densities of the Sahelo-Sudanian area (Badiane 2006). Since 1959, it was already exceeding its theoretical cattle support capacity (about 8 bovine per hectare) (Lericollais and Faye 1994) and kept up growing, following the population booming model (Courtin and Guengant 2011). Livestock headcounts thus required higher fodder resources.

Wooded layer was, in the traditional system, an essential fodder component during the hunger gap[g] (Fall-Touré et al. 1997, Courtin and Guengant 2011). *Acacia albida* (newly called *Faidherbia albida*) has especially a major role thanks to its reversed phenological cycle. Indeed, it loses its leaves during the rainy season and provides fodder during the dry season and therefore do not compete crops for photosynthesis (Fall-Touré 1997).

However, the wooded fodder resource reduction is the fact of excessive exploitation for energy and farm machinery impact on young seedlings. The territory could not host its herds on fallow lands during the rainy season because this area was required for subsistence crops. Therefore, transhumance length has been progressively extended (Garin et al. 1990, Lericollais and Faye 1994, Dia et al. 1999, Badiane 2006, Lalou and Grémont 2012) which, in turn, decreased the second household energy source availability after wood: dry animal dung used as combustible for meals preparation (Garin 1990, Dia 1999, Lericollais 1999, Reiff and Gros 2004, Badiane 2006).

Numerous projects were developed toward reforestation establishing communal tree nurseries around Niakhar nonetheless, they have all been abrogated (Ngom 2006).

2.1.2.1 Sols impoverishment

Livestock, tree and crop dissociation critically affected soils fertility. Indeed *Acacia albida* is a vertical biomass transfer major actor (Lericollais 1999) while livestock is a major horizontal transfer actor. Quantitative manure decrease is worsened by wind erosion caused by bare soils (straws harvest for hunger gap animal feed), and qualitatively as manure traditionally benefited from nitrogen fixation by the ingested *Acacia albida* (Sidibé 1978, Rabot 1990, Fall-Touré 1997, Lericollais 1999). Biomass reduction from manure and trees was added to agricultural intensification to meet food needs what simplified rotation reducing fallows and enhanced farm machinery for cash crop development with state support (Jouve 2001) (see figure 3)

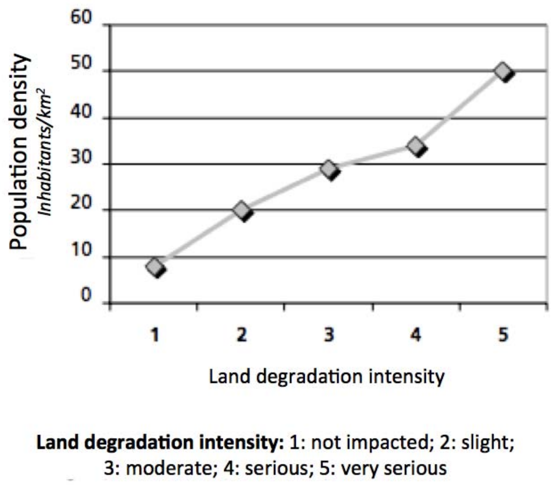


Figure 3: Land degradation intensity related to population density in Subsaharian Africa

Source: FAO 2003

Soil impoverishment seriously impacted yields (Jouve 2001). Nevertheless, it has not been the only factor impacting yields.

2.1.3 Land pressure through water issues

2.1.3.1 A decreasing rainfall in the 80's

Yield decrease was due to soil impoverishment but also waterfall decrease in the 80's. Indeed the former groundnut basin shifted from 600mm to 400mm waterfalls in a 50 years interval (Badiane 2006) leading the 400mm isohyet[g] to move 100 km South between 1930 and 1990 (see figure 4) (Cormier et al. 2000).

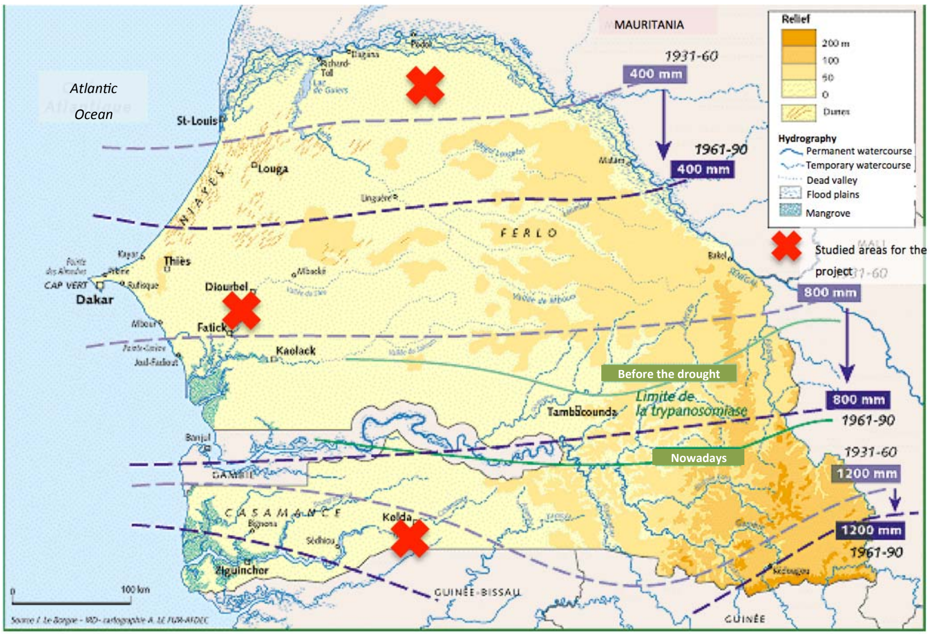


Figure 4: Isohyets translation during 1961-1990 droughts in comparison with 1931-1960 periods

Source: adapted from Cormier et al. 2000

As rainfall is essential for biomass production (see appendix 1), this transition weakened Northern rain fed cropping systems and therefore translated the groundnut basin South (Cormier et al. 2000). It also made fodder scarcer and increased subsistence crops area needs (Buldgen et al. 1992, Badiane 2006).

2.1.3.2 A salinity limiting cropping activities

In addition to water quantity, production also depends on water quality. Niakhar zone is affected by a very high salinity that can reach 0.5 to 3g of salt per litter in the seasonally flooded bottomlands (Badiane 2006). The most superficial layers, from 10 to 35 meters deep, are brackish nay salted. Counterbalancing salinity is very expensive and time-consuming as it requires layouts that have to be renewed every year to make freshwater (from 150 to 300 meters deep) available (Ngom 2006). Some village terroirs' salinity constrained their market gardening activities (Dia et al. 1999, Badiane 2006, Ngom 2006). Thus, some of them chose to develop further lucrative activities for the dry season to take advantage of the labour forces available at this period of the year (Lericollais and Faye 1994).

Facing the challenge of combining increasing food needs with soil impoverishment and waterfall decrease on a limited crop area, livestock fattening was perceived as a possible solution in some villages. Indeed, it does not compete with subsistence crops as animals are kept inside the compound for their entire journey, their diet is based on crop residues and imported concentrates such as rice or millet bran and a prepared feeding mix. Contrarily to transhumant and traditional herds, livestock fattening is less dependent on tree layer because the growth margin achieved enables livestock owners to import animal feed what turns the activity to be less contingent upon climatic hazards (Lericollais 1999). Mineral fertilizers remains too expensive to be widely used, transhumant herd manure is less available due to their shortened journey inside the terroir. Livestock fattening reintroduces this organic matter source without new surface area requirements.

2.2 Socio-political reasons

In addition to environmental facts, Senegalese policies modelled agricultural land use and agricultural practices.

2.2.1 Policies unfavourable to the traditional system

Fallow disappearance was not only motivated by surface area needs but also by legislation. In 1964, the National Domain Act stated that a land should be cropped every two years at least, otherwise, its property might be allocated to someone else by the rural community council. By this way, many fallows have been turned into cultivated lands for fear of losing property rights (Garin et al. 1990, Reiff and Gros 2004, Lalou and Grémont 2012) what partly explain their decline.

As seen previously, the State and international institutes particularly supervised the former groundnut basin. Close to the studied zone, Bambey ISRA's complex was created in 1921 and was hosting foreign research centres, especially French institutes related to the country colonial past. In those days, a significant number of research program were working on groundnut in this experiment centre.

From 1967, the State started a disengagement process cancelling preferential prices (Lericollais 1999), in 1978 seed supply stopped and in 1980 the cooperative were dissolved (Reiff and Gros 2004) what ended with the NAP (New Agricultural Policy) in 1984 aiming at reducing government interventions in agriculture (Reiff and Gros 2004, Ngom 2006). Institutional framework, assistance for producers and financial support through NGOs strongly fell from there (Ngom 2006). Bambey centre is considerably less dynamic than in the past by now and Sine region's inhabitants had to develop alternatives to this agriculture policies transition by themselves.

On another side State also impacted meat production. From 1992 to 1994, meat imports had almost been divided by 4. Between 1960 and 1995, meat availability *per capita* fell down from 20 to 10kg since production could not fit with population growth. The State guided its policies toward meat sector intensification to reach the goal of 13kg *per capita* in 2000 (Fall-Touré et al. 1997).

A supervision company that wished to develop bovine-draught fieldwork also introduced animals in the 70's. Nevertheless, oxen have been diverted from their proper use being fattened. This custom has been extended and made durable from then (Garin et al. 1990).

Nevertheless, policies could not have influenced local population without adjacent social changes.

2.2.2 From Sereer culture to Islamization

Transhumant herd has a strong social and spiritual value in Sereer culture. It is a sacred accumulation commodity which commercialization traditionally should be a means of last resort. It is reserved to self-consumption as sacrifice for weddings, baptisms, circumcisions or funerals. It is also dowry exchange commodity for bride's family. When herds used to stay on fallows during rainy season, milk was offered to any guest received (Lericollais and Faye 1994, Badiane 2006).

Islam extension, nowadays adopted by 76.5% of the Senegalese has developed trade trends, especially for ovine market. Indeed, all Muslim family buy a sheep for religious celebration what enhances livestock fattening activities 2 months before Tabaski (sheep religious celebration known as Aïd El-Khebir for the rest of Western Africa) (Buldgen 1992, Reiff and Gros 2004, Ngom 2006). This practice was then extended to bovine livestock.

These commercial trends also impacted traditional communal terroir management.

2.2.3 Toward household individualization

Sereers are gathered in compounds inside their village. Each compound is surrounded by a fence and directed by a compound head. One or several households, defined by sharing their meal everyday, are grouped together within a compound. Household is composed by the household head, his wives, his children and sometimes other family members such as nephews, cousins, household headman's mother or sisters (Reiff and Gros 2004). Transhumant herds are compound-owned while fattened livestock is usually the household property.

Since cash crop developed Sereer society slowly started to individualize. Groundnut development enhanced monetary valued transactions and young men and women could gain access to independent incomes cropping their own fields (Jouve 2001). Since the groundnut market has been declining Sereers have been looking for new commercial products to develop, many households split up (Ngom 2006) thus reducing the household UAL (Utilised Agricultural Land) on average. Tensions appeared around common goods leading some traditional collective rules to gradually vanish. For example, fertilization turned from a collective state (using common grazing[g]) to an individual state (applying mineral fertilizers), uncle to nephew herd transmission is being abandoned (Badiane 2006), transhumant pastoralists are progressively excluded from the Sereer agricultural system with cattle crossing corridors delimitation. As a consequence, flocks are directly guided to low population density areas and do not stop their herd to pasture on the terroir anymore (Jouve 2001).

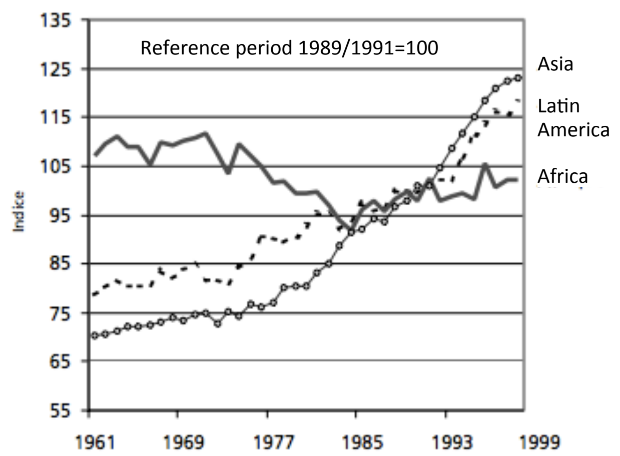
This household individualization promoted the commercial livestock fattening practice that generates substantial gains contrary to transhumant herds that are exceptionally marketed.

2.3 Economical reasons

If the cropped land area increased by 15% in 20 years, rural population growth reached 50% (Lericollais 1999). The system orientated toward import strategy to meet food needs.

2.3.1 An opening shifting system

Senegalese diet evolved a lot. Previously based on millet, self-sufficiency had been waning with groundnut cropping for export which land use has been compensated by high broken rice imports. The population now depends on wheat and rice, part of the daily diet and main component of the national dish: the *ceebu dien* (FAO 2010). This new food behaviour creates a high demand on foodstuffs disconnected from the offer formed by millet and sorghum (Lericollais 1999). Rice is imported from Asia that takes advantage of its production *per capita* booming compared with the African production stagnation (see figure 5).



Source: Statistical Analysis Services, 2000

Figure 5: *Per capita* food production regional trends from 1961 to 1999

Source: adapted from FAO 2003

It generates elevated cash flows requirements for households to get these commodities (Lericollais 1999, Ngom 2006), even more as they are particularly linked to the global market price volatility (FAO 2010).

2.3.2 A major economic attractiveness

Livestock fattening has now been practiced for 50 years and makes work pay as the 1st source of income in Niakhar area (Lalou and Grémont 2012, Vandermeersch 2013). It is a quick return on investments (Lericollais 1999) enabling them to gather the monetary requirements for their households. Economical attractiveness must be one of the first reasons that might explain producers' enthusiasm for livestock fattening.

2.3.3 A strong market access

Livestock fattening could also be developed thanks to a strategic market position providing many outlets. The studied area is between two major urban centres (Bambey and Fatick) and can access numerous weekly markets such as Bambey, Diourbel, Sandiara, Niakhar, Fatick, Diohine, Patar, Mbafaye, Dara Djolof and Toucar (see figure 6) (Lericollais 1999, Badiane 2006).

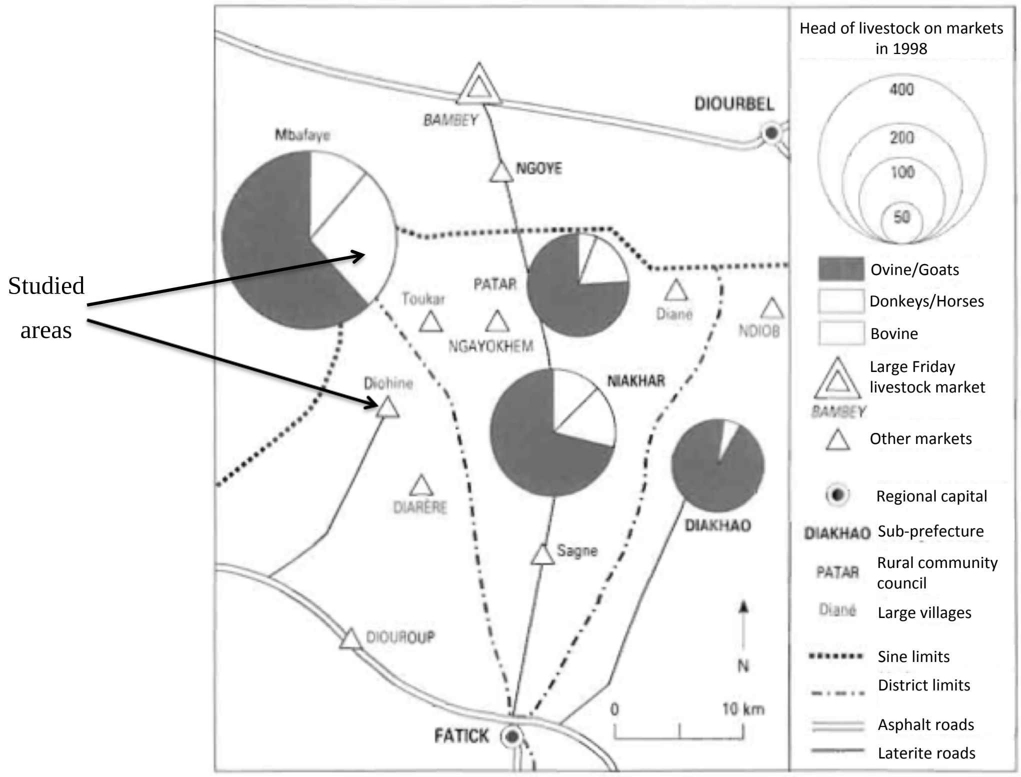


Figure 6: Weekly livestock markets of Sine in 1998

Source : adapted from Lericollais 1999

The area benefit from a transport infrastructure network relatively high with 3 asphalted roads: Fatick-Niakhar, Niakhar-Bambey and Diohine-Keur-Martin (Ngom 2006) and the villages are close to the main livestock road joining Mauritania to Dakar and can take advantage from this livestock market network.

2.3.4 Investment favoured through migration

Even though livestock fattening requires high initial investments, terroirs' position also helped households for livestock purchase by means of migration. Indeed, the high Sereer mobility, ranked second after Peul ethnic group (Badiane 2006), has been particularly stepped up by isohyets translation, biomass reduction factor (Cormier et al. 2000). Young people of the area are seasonally working in Dakar to cope with food insecurity (FAO 2010). They send a large part of their income to their native village. These savings can help funding animals and concentrates purchases for livestock fattening (Dia et al. 1999, Ngom 2006).

3 Issues and assignments

3.1 Issues

The former groundnut basin has been subjected to a fast and important agricultural transition from the 60's (Lericollais 1999). As mentioned previously (see part 2), the evolutions resulted from physical, social and economical environment changes. In CIRAD's intervention area, two different terroirs were studied based on their distinct reaction facing a similar environmental change. These terroirs are Diohine[1] and Barry Sine. Diohine conserved traditional fallow system and could therefore maintain a relatively traditional extensive livestock system based on free ranging and local resources valorisation. In contrast, fallow almost disappeared from Barry Sine and inhabitants mostly practice off-season livestock fattening. About 80% of the compounds practice it for only 20% in Diohine (see figure 7).

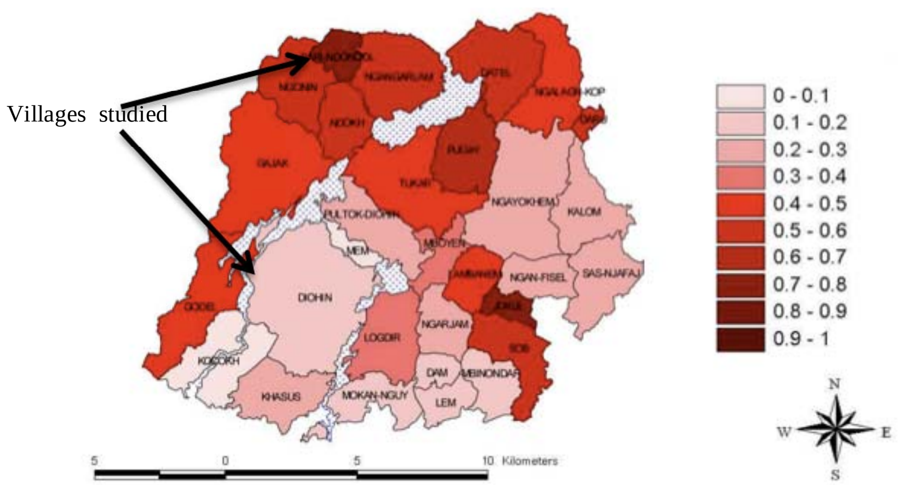


Figure 7: Compound proportion applying livestock farming fattening in 2012 in the different terroirs included in the Niakhar IRD demographic observatory

Source : Delaunay and Lalou 2012

Concerning physical environment, previous rainfall decrease, soil impoverishment by agricultural intensification, progressive rangelands and fallow disappearance (Garin et al. 1990, Reiff and Gros 2004, Ngom 2006, Lalou and Grémont 2012) accelerated tensions about local resources use, fodder resources in particular and real estate. In the traditional system, herds had a predominant role in soils fertility and yield maintenance. Indeed herds, beside their essential social

[1] Diohine case will be taken as Sassem neighbourhood to consider an equal number of compounds than for Barry Sine, because this neighbourhood is specialised in agriculture and has adjacent fields from the village centre to the wetland.

function, secure organic fertilisation and therefore next year millet yields. Transhumance reduces surface area benefiting from soil-enriching agent and increases *Striga hermonthica* and aerial erosion. Fattening was an opportunity to maintain livestock farming activities in a resources-limited terroir mobilising external resources (imported concentrates) (see appendix 2).

Concerning social patterns, livestock-fattening development was promoted by islamisation (98.1% of the inhabitants are Muslims in Barry Sine for 40.8% in Sassem neighbourhood in Diohine (IRD 2013)) that introduced ovine farming for rituals and livestock trade in the customs. Moreover, household individualization, demographic pressure increase and diet orientation toward imported foodstuffs that are not produced locally augmented monetary needs.

Finally, from an economical insight, groundnut decline (principal cash crop) and State disengagement from agricultural production required new income-generating activities development that could not be counterbalance with market gardening as off-season activity in Barry Sine because of high soil salinity (impossibility to irrigate). Fattening activities were developed for this purpose in Barry Sine. Even if it requires high initial investment (animal purchase to be fattened) and regular cash flow (concentrate purchase), Barry Sine could overstep by a large young part migration to Dakar, source of liquidity. On another hand, the area is well positioned to take advantage of the offer and meet the demand of the local markets connected to large towns such as Dakar and Thiès.

Knowing the on-going population growth, climatic change, environmental deterioration, market regionalisation (nay globalisation) processes and observing that national food security is still not guaranteed, agricultural intensification (both crop and livestock) will be investigated. In soils impoverishment and yield stagnancy context, noting that extensive bovine herds progressive disappearance in the groundnut basin moved deeply soils fertility management system, it is relevant to wonder how the different agricultural strategies adopted by Barry Sine and Diohine villages can impact terroir's environmental sustainability. We will question nowadays the interest of i) maintaining traditional system remainder adapted to new environmental constraints (Diohine case) ii) or favouring new fertility management rise structured around bovine fattening (Barry Sine case). These divergent managements impact biomass and nutrient flows differently according to the analysis scale adopted: plot, household or terroir scales. Nutrient and biomass flows analysis informs each scale functioning while nutrient balance is a largely admitted environmental sustainability indicator (Roy et al. 2005). In other words, we will focus on system opening multi-scale effects on nutrient balance and especially for the terroir scale adopting a systemic approach.

To be able to plan agricultural future of the former groundnut basin, it is primordial to consider actor's terroir perception in terms of soils fertility evolution and to grasp the fertility management practices evolution dynamics in order to increase production. In that purpose, a multiple perspective analysis that distinguishes both terroirs (Barry Sine and Diohine) and genders (men and women) will be necessary to take into account the different social status distinction, their role within the household and their position into agricultural activities.

3.2 Assignments

In order to understand the current agricultural system's functioning (soils' fertility management in particular), to evaluate their environmental sustainability and to reflect on future improvements, the project assignments consisted in:

- 1: Gathering quantitative data required for a biomass flows and nitrogen balance at plot, household, and terroir's scales for Barry Sine (a similar work was already hold in Diohine in the frame of another internship)
- 2: Processing the data in the form of nitrogen visible balance at the 3 different scales (a similar work was already hold in Diohine in the frame of another internship)
- 3: Comparing the biomass flows and nitrogen balances obtained for Barry Sine and Diohine
- 4: Presenting the multi-scale balances results and grasping qualitative terroir perception possible improvements considered by stakeholders from each terroir.
- 5: Analysing men and women perceptions in each terroir related to current and future terroir management and soil's fertility (inter-terroir and inter-gender perception's comparison)

PART 2: Methodology

4 Global approach

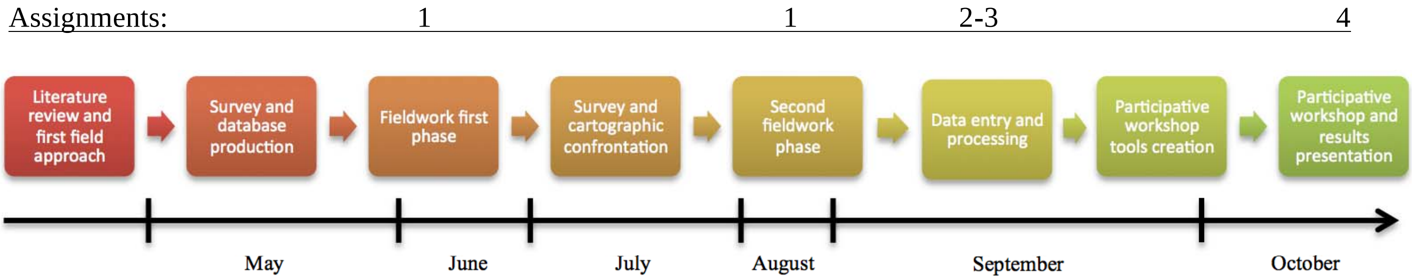


Figure 8: Chronological distribution of the tasks to fill the internship assignments (first line)

The project took place on a 6 months basis (April to October). The step to prepare the first fieldwork was based on literature review that focused on agricultural practices in the former groundnut basin, their evolution as well as the different kinds of agricultural system models. This phase was interspersed by a 4 days fieldwork to present the project to local authorities, the village headmen as well as IRD's investigators working on Niakhar area. From the observation we made in both villages and their surrounding and from the literature review, we could adapt the survey guide and the database to the local context.

The first assignment (data collection) was divided in two phases. During the initial fieldwork we administered the survey to Barry Sine's 73 households. In parallel a Senegalese cartography student also collected information about the plots and their GPS landmarks independently. This fieldwork was followed by data comparison to index missing data and correction to be collected during the second fieldwork.

The second assignment consisted in entering, processing and comparing data to compare villages' results (third assignment). The results were used to create communication tools. These tools were used for the 4th assignment in order to facilitate interactions and to grasp villager's terroir perception in the present time and for the future (see figure 8).

The 5th assignment (compare the results by village and by gender) took place after the six months spend in the CIRAD.

5 Conceptual model

The conceptual model choice was preceded by a literature review about the different kinds of biomass flows conceptual model and representation. We then selected the most adapted solutions for the studied area.

5.1 The different kinds of conceptual models considered

Agricultural systems representations are simplification of complex systems to make them intelligible and possible to study. Thus, a single system can be illustrated in different ways with models according to the communication goals.

It can be based on mathematical models, processes or actors (Belem et al. 2011). In fertility transfer flows case, should appear:

- the vector (flow support)
- the start area, the arrival area (origin and deposition point of the matter)
- the quantities withdrawn and returned
- the intermediate transformations and the elements returned quality
- the induced effects (Rabot 1990)

5.1.1 Plot, individual or herd scale

The plot, individual or herd scale is generally based on experimental data (Thornton and Herrero 2001). It is composed by detailed sub-models also called « laboratory » models (Vayssières et al. 2009b). The main system’s simplifications observed concern sylvopastoralism sector (especially organic matter inputs from pruning) and practices such as mulch or green manures. Concerning subsystems, biophysical mechanisms are generally simplified excluding phenomena such as exudation, roots decomposition, fallows litter production, erosion, runoff, lixiviation, atmospheric deposition, biological nitrogen fixation and gaseous losses (Manlay et al. 2004).

This scale does not transcribe the three farm sub-systems, that is to say social, economical and environmental components (Thornton and Herrero 2001). This simplification might explain why plot strategy is difficult to generalize (Tittonell et al. 2006).

Extrapolation from one scale to its upper one (proportionally to the surface area or headcounts (Schlecht et al. 2004)) can consider the relationship between its sub-systems (Thornton and Herrero 2001) but in many cases does not when based on theory which states that « the all is the sum of its part».

5.1.2 Farm scale

The farm scale, taken as the household scale in our case, comprises inflows and outflows from external origins or destinations such as purchases on markets or village exchanges but includes plot scale and therefore do not represent flows from the housing to the fields (see figure 9).

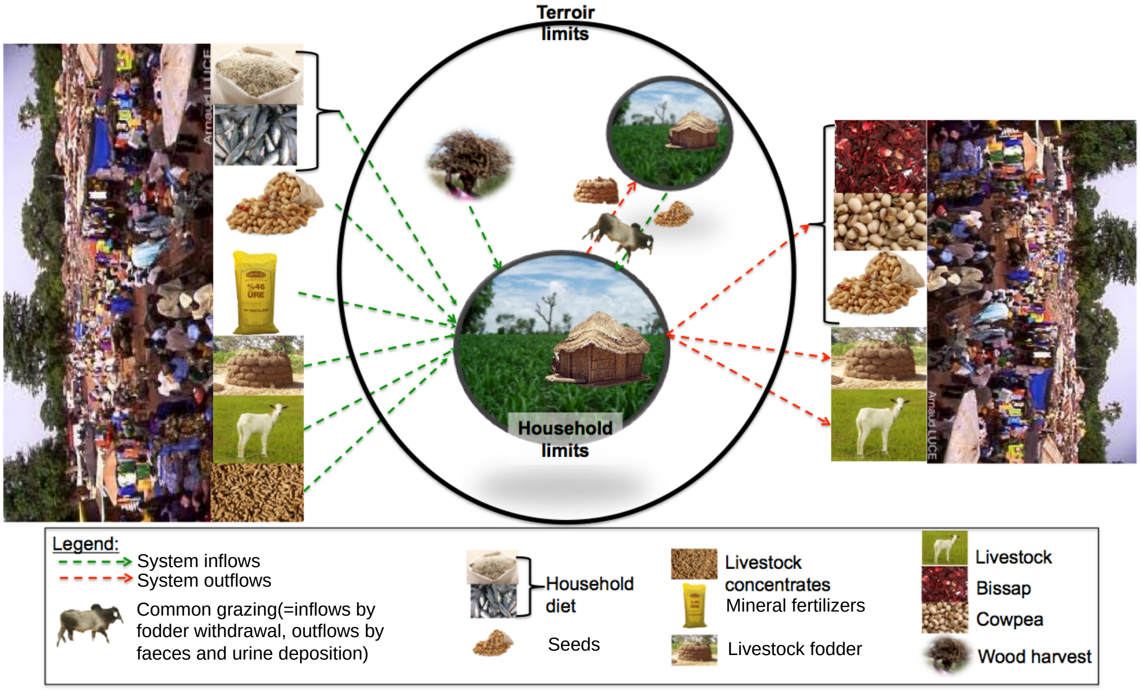


Figure 9: Biomass flows exchange between the studied household and its environment (other terroir's household, external markets)

If not considered as a global unit, the farm scale can be divided into agricultural sectors which results are then added up. According to the disciplines the researcher gives priority to, the model sector's cutting up or the level of detail might diverge.

For agronomical approach the soil sector is isolated and the model details its biological processes (Thornton and Herrero 2001, Schlecht et al. 2004, Lisson et al. 2010).

An anthropogenic approach will isolate household sector and, as a field model (Vayssières et al. 2009a) or an action model (Vayssières et al. 2009b) will include social parameters (as labour availability) (Thornton and Herrero 2001, Lisson et al. 2010, Belem et al. 2011), qualitative criteria that transcribe producer's behaviour predictability and decisional rules (practical seasons or management options (Thornton and Herrero 2001, Vayssières et al. 2009a)). Nonetheless, some human activities are rarely included such as combustion and handicrafts (Dugué 1985). Self consumption is generally simplified ignoring secondary products (cotton bolls, groundnut pods, construction wood) (Manlay et al. 2004) and farm machinery is not commonly inserted in modelling (ILCA 1998).

An economical approach will widen system's boundaries to non-agricultural incomes (Lisson et al. 2010).

Vocabulary employed to describe the farm scale limits can be confused. It is sometimes called "agricultural system" without defining its boundaries (Thornton and Herrero 2001). Some models use indifferently "compound scale" or "community scale". Some of them such as TAMU Beef are applied either to farm or to village scale (Thornton and Herrero 2001), thus farm and terroir scale differentiation is not transcribed and farms interactions consideration might not be guaranteed. Others do focus on terroir internal flows between the stakeholders. Their sub-division can separate livestock farmers from crop farmers or sedentary livestock farmers from transhumant pastoralists to highlight herd size impacts on crop farmer's vegetal biomass (Dugué 1985, Manlay et al. 2004).

5.1.3 Terroir scale

5.1.3.1 A varying terroir definition according to the disciplinary

The disciplinary approach adopted is critical for terroir systems' limits determination.

For geographers, "terroir" corresponds to "homogeneous plots group characterised by their similar structure, ecological dynamic and agricultural design". The concept is defined by its production ability, its distance from the households and collective decision-making (Rabot 1990).

According to Africanists, the terroir is a « cropped area used by a village community» (Rabot 1990).

For Agronomists, it is a yield potential and is divided in ecological zones (bottomlands, Piedmont…). In a homogeneous environment case, "terroir" concept is related to the distance from housing.

In administrative terms, "terroir" is defined according to administrative borders, nevertheless, this approach is limited, especially in Africa while real estate is not always a good representation of the real soil use which is bounded by symbolic elements (Rabot 1990).

5.1.3.2 Terroir scale sub-division

Terroir scale's results can be represented in different ways if the focus is made on entity or spatial units.

Representation based on entities focuses on the terroir as a whole. Usually, household are sampled (randomly, *per* household type or *per* extremes) and results are extrapolated (rarely explicit in scientific articles) (Dugué 1985, Schlecht et al. 2004, Tittonell et al. 2006 Vayssières et al. 2009a, Lisson et al. 2010, Rufino et al. 2010).

Representation based on spatial units helps observing agroecological areas interactions. Herds organic matter deposition during common grazing can be distributed proportionally to the compound surface area or more precisely according to the real herds track (Schlecht et al. 2004, Rufino et al. 2010). For non-common grazing-based flows, spatialisation can be allocated by agroecological zone (Manlay 2001) (see figure 10) or by housing distance (separating hut fields from bush fields) (Tittonell et al. 2006).

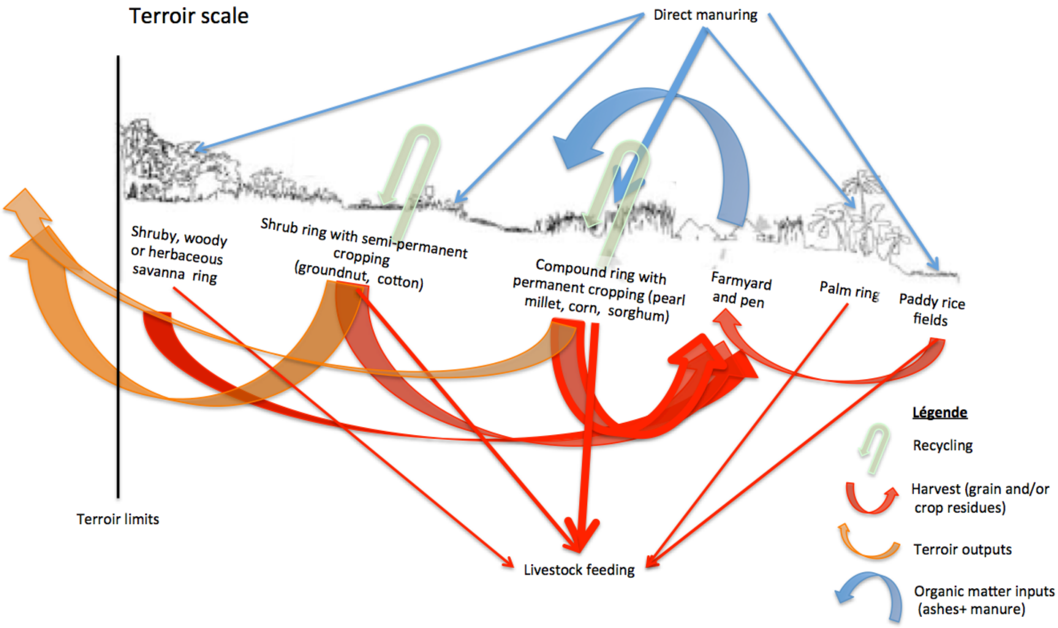


Figure 10: Biomass flows spatialisation synthesis

Source : adapted from Manlay et al. 2004

5.2 The conceptual model chosen

Considering the different biomass flows representation options, we opted the above model (see figure 11).

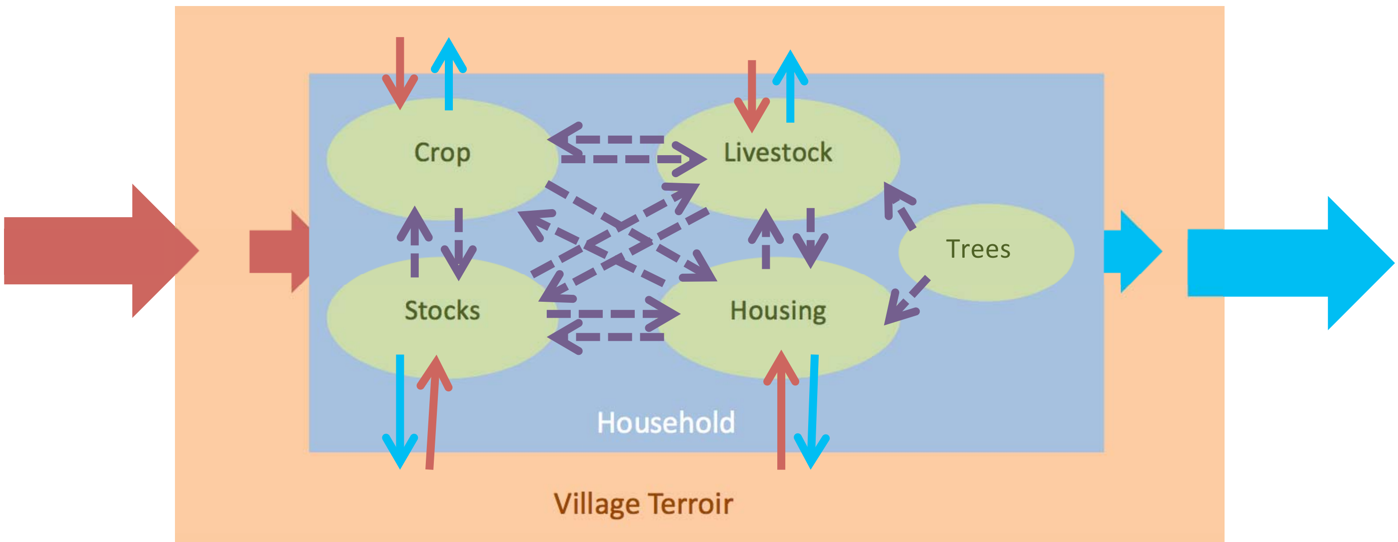


Figure 11: Biomass flows spatialisation synthesis

Source : adapted from Odru 2013 and personal 2013

5.2.1System's limits

Adopting a systemic approach, we selected the Africanist' definition of "terroir" (« cropped area used by a village community» (Rabot 1990)), system's limits were though set during the preparatory fieldwork. They have been determined in agreement with the village headman who indicated to us the traditional village boundaries. We then administrated the survey to all the households included in these limits.

For the plot scale, we considered all fields that had been used in 2012 by the surveyed households (either for crops or fallows) excluding the surface area crossed by transhumant herds which were not located within the UAL. Indeed, in Barry Sine's case, the traditional village limits only includes hut fields while households usually also have bush fields. Plots could therefore be either owned or rented by the household.

5.2.2Spatial approach

Spatial fertility transfers have strong consequences in Sudano-Sahelian area what motivated the decision to consider them in the study (Rabot 1990). We wanted to highlight that distance between the plot and the household is major in fertility management through map representations. As Barry Sine's agroecological zones are simpler than those of Casamance studied by Manlay (2001), common grazing is therefore approached proportionally to the surface area while nitrogen balance is plot-scale precise.

5.2.3 The household scale agricultural sectors considered

« Crop » and « Livestock» agricultural sectors were isolated since Barry Sine is not only conserving transhumant herds but also developing livestock fattening related to import-based soil-less breeding. The herd has been considered batches *per* batches that are either owned or shared by the terroir households in 2012.

The « Housing » is isolated has a sector by itself to conserve an anthropic approach. Like so, we could assess household self-sufficiency as the system is particularly open to foodstuff, concentrates and animal flows. It integrates at the same time the household structure and the farm machinery which are essential in organic matter flows.

The "Tree" sector is isolated considering its major role during the hunger gap, especially for the *Acacia albida*.

6 Survey data collection

6.1 Investigative guide structure

The investigative guide has been developed around the different conceptual model sub-systems (see appendix 3).

6.1.1 Household structure

The questions developed around the household structure are interested in the creation data of the household and in the household headman age. The survey also tackles household's population composition that reflects both the labour available and the food needs (conversion in labour unit LU and feed unit FU are listed in appendix 4). Considering population mobility, headcounts are evaluated *per* month and then reported *per* year. A second part inventories household's commodities including farm machinery, the plots used in 2012 and the animals within the compound or confided at the survey date. Finally, the last part focuses on the household foodstuff purchases and combustible use.

6.1.2 Cropping system

The whole inputs (seeds, mineral fertilizers, manure, night paddocking[g]) and outputs (grains and by-products), their origin and destination are questioned for each plot listed during the household structure part. The kind of exchange is indicated (donation, purchase or exchange). For straws, quantities for animal feed are distinguished from quantities for construction. In fallow's case, we study their length and the reason why they were set.

6.1.3 Livestock system

From household's structure part, we ask *per* batches for animal products (livestock and milk) yearly purchases, sales, exchanges, donations, with their origin and destinations. We also ask for the birth, mortality and thefts. Headcounts were then converted into TLU (Tropical Livestock Unit) (see appendix 5).

Herd localisation is fallowed along the year at the agroecological zone scale (hut fields, bush fields, wetlands) for each livestock practical season, that is to say for each feeding or herd localisation change.

Finally, animal feeding is studied *per* livestock practical season and batch in terms of quantity and also quality (nature and origin).

6.1.4 Effluent management system

The survey assesses the storage mode for organic matter reserved for plot fertilization. The household headman indicates to us if the organic matter has been directly carried on the plot or stored on a dunghill and transported later on. For the wastes swept from the yard the questions are interested in the location where the basin were poured (hut or bush fields).

6.1.5 The trees

The tree variety composition is studied for each plot. Animal feeding and wood harvest as combustible for meal preparation assess the tree resource utilization.

6.2 Investigative guide administration

To fit with Soft System Methodology[g], investigative guide administration was adapted to local conditions.

6.2.1 System comprehension by immersion

The fieldwork phases were 3 months long, that is to say half the all mission length. The accommodation, in Diohine, allowed us to understand the local living conditions (Pretty 1995) and inherent system's constraints (Wezel and Rath 2002).

The investigative guide was applied to the whole 73 households in collaboration with the French/Sereer/Wolof translator. Direct contact with producers favours system approach as a whole, terroir management choice comprehension including social, economical and environmental factors (Pretty 1995, Wezel and Rath 2002). System analysis can therefore be based on actor's local knowledge (Sriskandarajah et al. 1991, Wezel and Rath 2002).

6.2.2 Survey period

The investigative guide administration took place from May to July what corresponds to a less time-consuming agricultural period of the year. Indeed, at this moment, households are more available as the only tasks to achieve are crop residues raking and burning. We could also attend the first millet seeding while ending the first fieldwork.

The second fieldwork phase took place in August. We then had an overview of vegetal cover evolution in comparison with May (the end of the dry season) and August (the middle of the wet season) (see appendix 1).

6.2.3 Project presentation

Niakhar zone comprises an IRD centre devoted to population monitoring. Villagers are regularly solicited for surveys (every trimester). Project presentation was therefore a primordial step to work fittingly in the area.

First, the study goals were exposed stressing that the project was delivering its results as a time-spent compensation but not any kind of commodity. Indeed, the hope to freely receive mineral fertilizers, animals or foodstuff could lead the participants to under-value their harvest, herds or input uses.

To get actors interested in the process and to make it credible, we started by localising their compound on the village aerial map. This step also familiarises them with this communication tool that we will use later on. Relevant terroir management information was also gathered during the map lecture.

The project being led in partnership with the IRD, the family genealogy is presented to the stakeholders. It provides a first feedback on research hold in the area before the participative report and facilitates data collection about family composition. Indeed, the survey is long and household headmen are not used to count all the members of the household. It demonstrates our knowledge of the area, indicates our respect toward the family and involves them in the process.

6.2.4 Investigative guide administration distribution

Men have little knowledge about women and children farming activities (Vandermeersch et al. 2013). On the basis above, in order to gather the most precise information as possible, the survey has been divided. Questions about poultry farming, bissap or cowpea as well as wood harvest are administrated to women while other crops (including cowpea hay) and livestock farming are asked to men. To fit with local social rules, we started the survey with the household headman. By this way we could also lighten the time needed for woman's survey as they are usually very busy and cannot provide us information without receiving clearance from the household headman.

If women provide us contradictory information compared with men (for plots where cowpea or bissap were sowed for example), we conserved the crop-specialist answer. Indeed, in some case, men do not want to tell us that they did not give permission to sow a plot. In other case, the husband do not exactly know which plots benefited from inter-cropping especially if children harvested the cowpea hay.

6.2.5 Dealing with culture differences

6.2.5.1 Broaching dates questions

Dates were important to understand how the biomass-flows-generative agricultural practices were distributed through the year to refine terroir management. However, in Barry Sine, catholic calendar is not commonly employed. We used Muslim celebrations such as Magal, Gamou, Toucar's Raan celebration, Ramadan, Korité, Tabaski and Tamkhalet as temporal references to facilitate the communication.

6.2.5.2 Broaching livestock questions

As notified previously, questions about herds are sensitive. Because of social and gender ladder and bilinear society functioning, the investigated could under-value herd headcounts (Vandermeersch et al. 2013). Local believes tend to fear villagers from revealing their stocks not to attract the "evil eye" or bad luck (Badiane 2006, Vandermeersch et al. 2013) and counting livestock headcounts is taboo. Finally, a tax was founded during the colonial era proportionally to the herd headcounts. Although this tax is obsolete for a long time now, reluctance still persists in revealing the livestock headcounts (Badiane 2006).

We tried to isolate as much as possible the interviewed to facilitate data collection and not to push around local traditions. Questions are organised progressively to broach the livestock headcounts. First, we assess milk production and the number of milked animals. We then ask for the number of bulls to end with the non-milked cows. If the last question is problematic we use ranges not to ask directly for the exact number of heads.

6.2.5.3 Broaching questions related to household financial health

Generally, households with few financial means that cannot buy animals can resort to *pok*[9]. They receive an animal and return part of its offspring to the owner. Thus, *pok* is an indicator of the household financial health and is therefore also a sensitive question. Not to disturb the interviewed, we first ask him if he confided animals to another household and then we ask him if he received animals.

Millet and meat purchase are household wealth indicator as well. It is therefore preferable when tackling foodstuff purchases to start by brightened up cereals such as corn, then other crops, fish purchase (generally accessible to all the households) to finally end with meat.

7 Data basis and indicators calculated

Data processing requires adjustments to compare the different biomass flows.

7.1 Data entry

7.1.1Metric units

Sereer villagers do not use the same measure units as Europeans. Indeed, the straw, the wood and the manure are counted in carts while the millet is informed *per* bale. The term "kilograms" used actually corresponds to different can sizes depending on the product measured.

To compensate for these metric differences, measurements were hold on Mbafaye market, close to the studied areas and visited weekly by all the households. A second measurement series was hold in the village itself. Missing conversion data were completed thanks to the literature review and especially Vandermeersch et al. (2013) study.

7.1.2Decision-making rules

When harvested products from different plots are stored together without measuring them separately beforehand production is artificially divided up according to the surface area for each plot. If the interviewed could not evaluate some harvested products but could either indicate the grain or the straw harvest, we estimated the missing data thanks to the grain/straw ratio. When neither the grain nor the straw productions were gathered, the missing data was estimated thanks to the terroir crop average yield.

7.1.3Common grazing internal biomass flow calculation

Households' interactions calculation by means of common grazing was divided in six practical seasons throughout the year to reflect herd management and fodder resources changes :

- fresh herb availability period that makes small ruminant night paddocking possible in non-cropped areas
- ovine fattening period coordinated with Tabaski celebration
- millet to groundnut grain harvest and labour-intensive period
- common grazing with shepherd period in groundnut fields only
- common grazing period possible on the whole territory after straw harvest
- small ruminant common grazing with feeding supplements by night in the compound

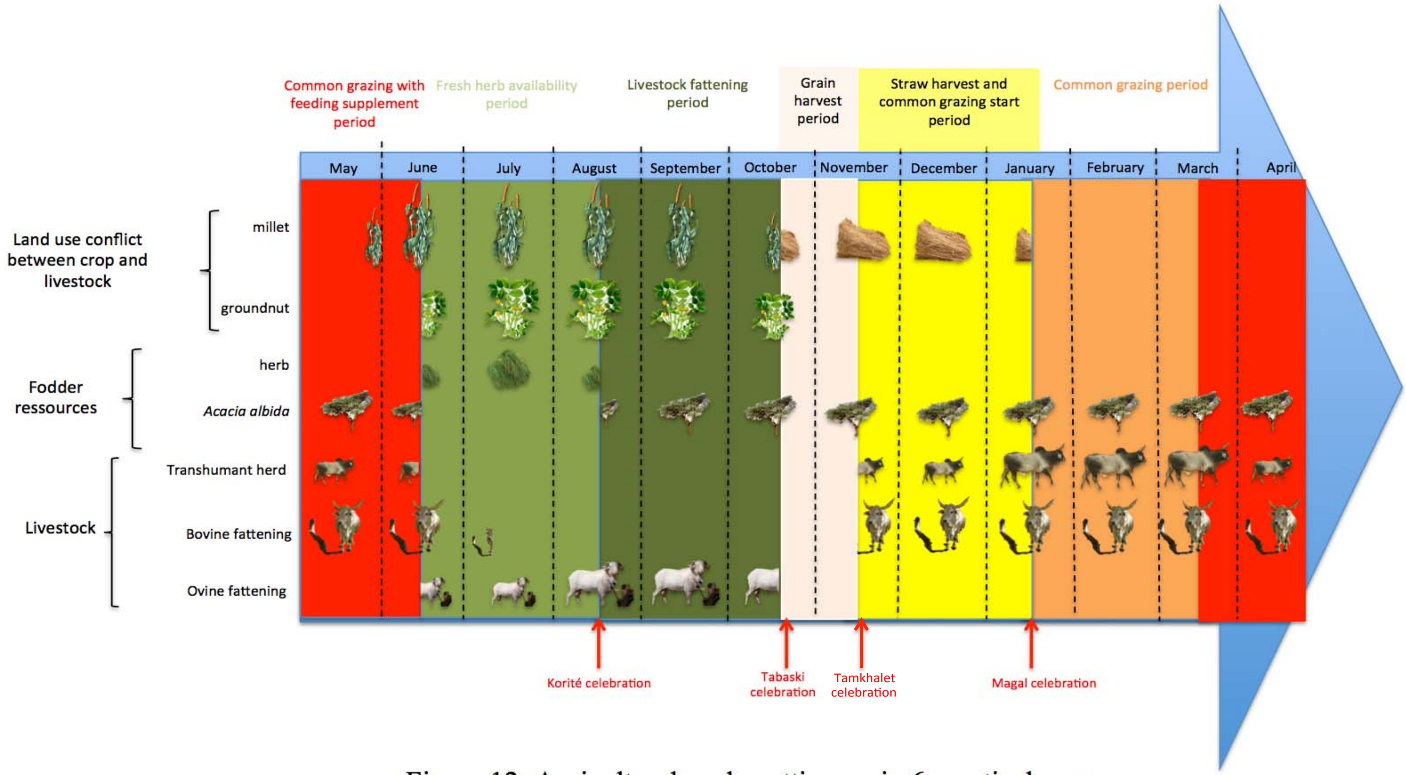


Figure 12: Agricultural cycle cutting up in 6 practical seasons

Biomass flows calculation between households related to common grazing are assessed with different criteria. First, we assess the residual biomass available on-fields after straw harvest. This quantity is approached comparing by-products harvest with theoretical straw production (based on straw/grain ratio from literature review (Manlay 2001)). If harvested by-products are inferior to theoretical by-products quantity, then part of the biomass has been kept on-field and is therefore available for common grazing. Because crop residues are not eaten entirely, a livestock consumption coefficient is applied to the residual biomass according to the crop type (see appendix 6).

A second step consists in assessing livestock withdrawal needs during common grazing. It corresponds to total daily needs from which feeding was cut away for each batch.

Finally, herds' needs are subtracted from available biomass for each practical season. The available biomass is updated at the end of each practical season in order to define the biomass available for the next season TLU.

To assess herd dropped of, both the seasonal TLU and the seasonal nitrogen content in faeces and urine were taken into account (see appendix 6 and 7).

After entering, data were processed to assess system's sustainability.

7.2 Data processing

7.2.1 Visible balance notion and efficiency

Agricultural intensification can threaten agricultural system's fertility if it is not combined with fertility maintenance. By this way nutrient balance is an interesting sustainability indicator (Roy et al. 2005). The visible balance consists in estimating annual inputs and outputs linked to agricultural activities collecting the information with the farmers (Simon and Le Corre 1992, Alard et al. 2002). This balance approaches the household as a whole contrarily to the CORPEN or BASCULE methods based on plot scale measures that are extrapolated afterwards. It does not use standardized norms and therefore better illustrates each farm particularity (Alard et al. 2002).

Some visible balances consider *Fabaceae* symbiotic fixation nitrogen inputs, volatilisation, mineralization and leaching outputs (Alard et al. 2002). This study focuses on horizontal biomass flows actually visible and assessable by the stakeholders.

The second fertility assessment chosen is efficiency calculation. This indicator is the division of the outflows by the inflows. It represents the "return on investment" as it points out for each units imported how many units were exported (Vayssières 2012).

7.2.2 Nitrogen choice as a fertility indicator

Nitrogen, compared with phosphorus and potassium is the most loss-making mineral compound in Sub-Saharan Africa in relation with plant needs (Bado 2002). It is the major plant growth factor as a basis for protein, nucleotide, nucleic acid and chlorophyll constitution. It has a major impact on soils fertility and is one of the most important minerals limiting Western Africa yields (Bado 2002). Indeed, cereal fertilization on Western Africa tropical sandy soils is principally based on drawing on soil organic nitrogen reserves, which are quantitatively finite and limited (Waneukem and Ganry 1992). Nitrogen has therefore been selected to represent soils fertility because of its predominant role in the studied area

Plot scale practices, nitrogen balance and efficiencies were then spatialised.

8 Result spatialisation

8.1 Transects

Transects help to identify global agroecological zones in order to understand terroir management. The daily commute between Diohine and Barry Sine during both fieldworks favoured soil, vegetation, and agricultural practices evolution observation.

A tour was traced from North to South and from East to West within the village traditional limits. It was travelled three times: in June, at the end of July, and at the beginning of August. Each time, pictures were taken in key sites to represent vegetal cover evolution from the end of the dry season to the middle of the rainy season (see appendix 1).

8.2 Partnership with the geographer and results confrontation

During survey data collection, a geographer proceeded to plot GPS landmarks (see appendix 9). To compensate for plots eventually forgotten, household headmen are asked twice and independently. If new plots are counted from geographer's survey, information could be completed during the second fieldwork.

Correspondence between surveyed plots and the georeferenced ones was based on a participative plan drawn with the interviewed, plot-household distance (bush or hut fields), sowed crops from 2010 to 2013, tree composition and finally, surface area estimation based on drilling machine round-trip number compared with the real surface area from GPS landmarks.

9 The presentation and participative workshop to explore fertility management innovations

The workshop main goals are to present results to the stakeholders, to launch reflection on terroir's management in terms of biomass flows and on terroir's fertility improvement opportunities applying a Soft System Methodology. Local actors participation lead to a better result understanding and interpretation considering their motivations, what matter for them within their social environment (Flood 2000). This step is essential to get actors involved in the process, to facilitate the work and the results appropriation to launch a group dynamic around possible improvements. Indeed, gathering stakeholders for the event strengthens social cohesion, dialogue and focus the attention toward a common goal: " how to improve soil fertility" (Sriskandarajah et al. 1991, Pretty 1995, Flood 2000, Wezel and Rath 2002). Finally, the workshop is a way to share local knowledge and ideas and, by this way, to create a common knowledge adapted to the local context (Sriskandarajah 1991, Pretty 1995, Wezel and Rath 2002).

9.1 How?

The mission was 3 days long (see table 1).

Table 1: Mission cutting up

Tuesday 08/10/13	Wednesday 09/10/13	Thursday 10/10/13
-Translator training -Adjustment related to their workshop perceptions	- Barry Sine workshop -Workshop debriefing with researchers and translators	-Diohine workshop - Workshop debriefing with researchers and translators

Beforehand, the translators were involved in thematic broached and the workshop tools construction. The translator-training step consisted in browsing the final workshop plan and the communication tools selected, gathering their point of view and adjusting it if necessary.

To perceive both men and women's point of view, seeing the bilinear social functioning, the workshop was divided in two steps (see figure 13):

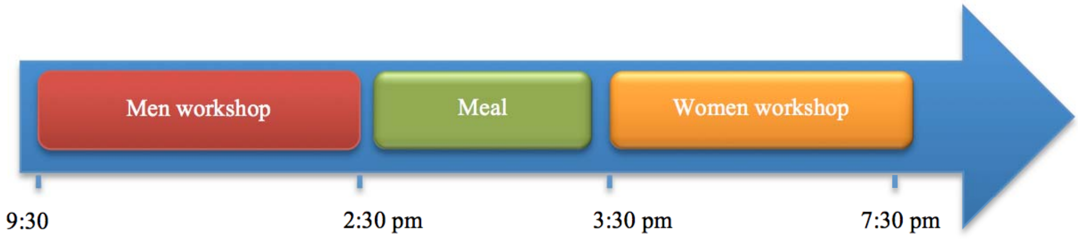


Figure 13: Workshop cutting up

Again, to fit with social norms, we started the workshop with men. The participants for the morning session are:

- Households headmen or household representative (73 for Barry Sine, 44 for Diohine)
- CIRAD researchers: Jérémy BOURGOIN and Jonathan VAYSSIERES respectively specialised in participative cartography and livestock/modelling
- 2 French/Sereer translators: we chose to conserve the translator who helped us to administrate the survey guide as they are familiar with the participant households, moreover they are a man and a woman what facilitate everybody's participation
- 1 engineer student

The workshop was hold in front of the village headman compound in Barry Sine. In Diohine, the event took place in front of Sassem public figure compound, the second social ladder figure after the village headman. Whenever possible, the place where the meal was shared was separated from the women's workshop site, thus, women are isolated from men and had the opportunity to express themselves. Women invitation is more open as the workshop took place during cowpea harvest period, a task added to the multiple women daily tasks that make them quite busy.

9.2 Soft System Methodology and OPERA method

OPERA method is a workshop facilitation tool. It turns the stakeholders in an active behaviour for result construction, favours actors participation and creativity (Slåen et al. 2003). The method was then adapted to the local culture, the time allocated, and the expected number of participants.

Thematic broached are first "What is?" that is to say the current situation, then "What could be" or the improvement imagined (see figure 14).

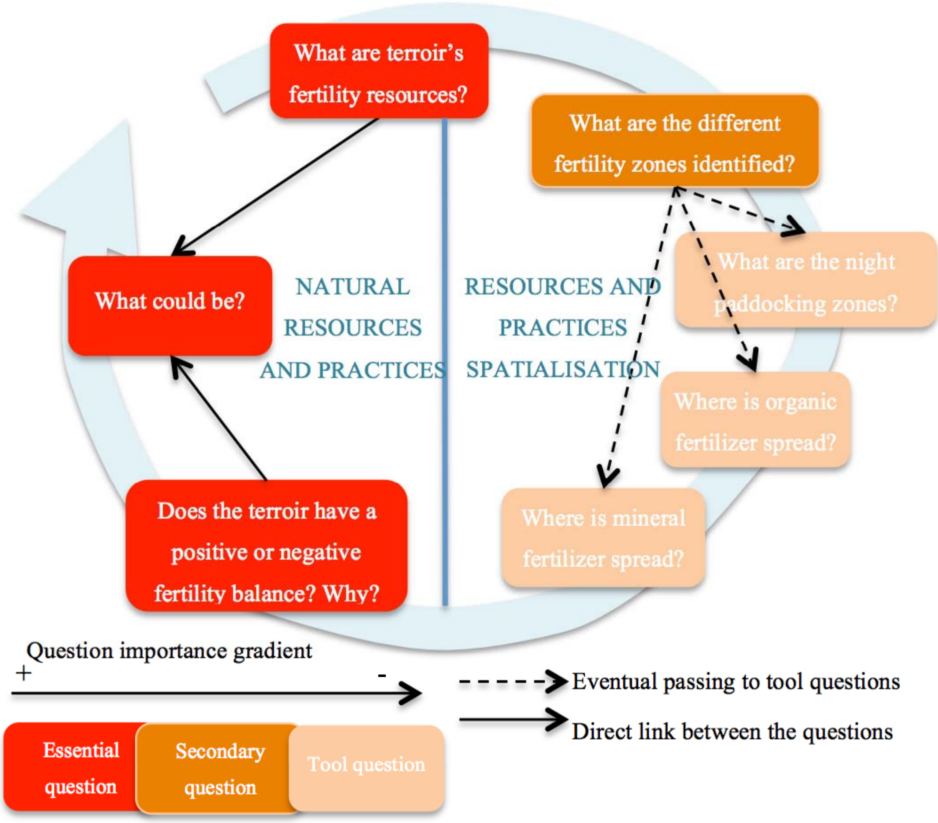


Figure 14: Workshop guide thread

Questions are oral rather than written to correspond to their own communication mode. We opted for the rich picture (Flood 2000) rather than mind mapping to counterbalance the language barrier and because visualisation through drawing balances dialogues and deepen discussions (Pretty 1995, Checkland and Poulter 2006).

We ensure that idea production is well separated from their evaluation to avoid frustrations and to maintain a security feeling to shape ideas. OPERA method was used for open questions that could generate multiple and diverse ideas (detailed afterwards). It is divided in two steps:

1) 20 minutes of exchange per groups of 15 participants and supervised by a facilitator

2) 20 minutes of plenary exchange with one representative for each group summarizing each group ideas

Researchers can shift from one group to another to perceive thought diversity that might not be presented integrally during the plenary exchange. Facilitators are also taking notes in each group.

Participative mapping is a tool that arises stakeholder's values, local and empirical knowledge. It enhances dialogue during multi-stakeholders meeting and is a communication basis for common commodities management negotiation such as territory (Burini 2009). Tracing paper medium has been selected rather than sand drawing to help information collection that will be analysed afterwards. In each group, a facilitator notes information after consensus to counterbalance the intimidation that can generate this medium and the tendency to concede the pen to an « educated» stakeholder (Chambers 2006). The maps are oriented and its different localities are shown to the stakeholders to facilitate their reading (Wiese et al. 2004).

The meal shared with the villagers aimed at compensating for the time they allotted us, specially for the workshop that took place at the beginning of millet harvest what requires large labour forces. A second goal was to reflect on the system opening up in terms of foodstuff questioning ingredients' origin. Indeed, only goat is produced in Barry Sine, goat and vegetables for Diohine.

9.3 Workshop detailed outline

9.3.1 Workshop introduction (20 minutes)

First, to create a confidence atmosphere, the researchers and the unknown translator are introduced to the villagers. Each researcher expounds its activity field. The program that framed the survey is reminded to contextualize the work done again and the workshop (Dia et al. 1999).

Secondly, the village history is read to create a suitable atmosphere for reflection and to get their attention. Indeed, Sereer's culture values especially its ancestors, it also comforts the actors-shared identity and reinforces their feeling of belonging to the group.

Finally, we ended by presenting the workshop outline so they can visualise thematic broached and will avoid digressions.

9.3.2 What is? (2h)

The current situation description is developed with open questions and tend to avoid stressing soil fertility issues (not to block off participants' ideas originality) and to shift their behaviour from learning to creating (Flood 2000).

It is developed around questions about terroir's structure (see table 2) and then about terroir's practices (see table 3).

Table 2: Participative workshop questions related to terroir's structure

Questions around terroir's structure (1h20)	**Method to collect villager's point of views**	**Goals**
-What are terroir's fertility resources (natural resources and practices)?	-Plenary rich picture creation -Vote by show of hands to rank the elements	-Analyse the availabilities -Favour positive reflection enumerating terroir's strengths to generate more ideas for the « what could be» phase -Accustom participants with terroir scale concept symbolising its limits on the rich picture
-What are the different fertility zones identified? (Dia et al. 1999)	Use of terroir aerial view map in A2 format, tracing paper and felt pens per groups of 15 participants composed beforehand Red represents less fertile spots, green more fertile spots (using the same legend that the nitrogen balance map presented afterwards)	-Create a confidence atmosphere within each group with OPERA method -Familiarise participants with the colour code used on the results maps -Observe the spatial fertility gradient perceived by the villagers
	Nitrogen balance presentation: -nitrogen importance for human and plants -nitrogen balance metaphor using cowpea to represent nitrogen, a bag to represent the soil. The balance is illustrated by adding up or subtracting cowpea from the bag (taken as soil's stock) to symbolize inputs and outputs Actors are invited to give feedbacks on the map comparison (the one based on surveys and the ones they generated during the workshop)	-Highlight differences between what was expected and what has been obtained -Underline eventual bias in the nitrogen balance methodology

Table 3: Participative workshop questions related to agricultural practices

Questions around agricultural practices (40 min)	Method used to collect villager's point of view	Comparison tool with survey results	Goals
Which areas benefit from night paddocking?	Plenary exchange directly: fertility balance map medium use	Night paddocking map presentation (tracing paper superimposition on fertility balance map)	-Highlight the different input's importance gradient from stakeholders point of view -Underline eventual bias in the nitrogen balance methodology
Where are organic fertilizers spread?		Organic fertilization map presentation (tracing paper superimposition on fertility balance map)	
Where are mineral fertilizers spread?		Mineral fertilization map presentation (tracing paper superimposition on fertility balance map)	
Does the terroir have a positive or negative fertility balance? Why?	Plenary exchange directly: Metaphor use comparing the village to a large household	-Terroir balance and its majors components oral presentation Actors are invited to provide feedbacks -Second village description, fertility balance map presentation Actors are invited to provide feedbacks	-Collect terroir's sustainability perception by the different stakeholders -Discuss about agricultural practices and their impact on terroir's fertility -Facilitate individual file reading

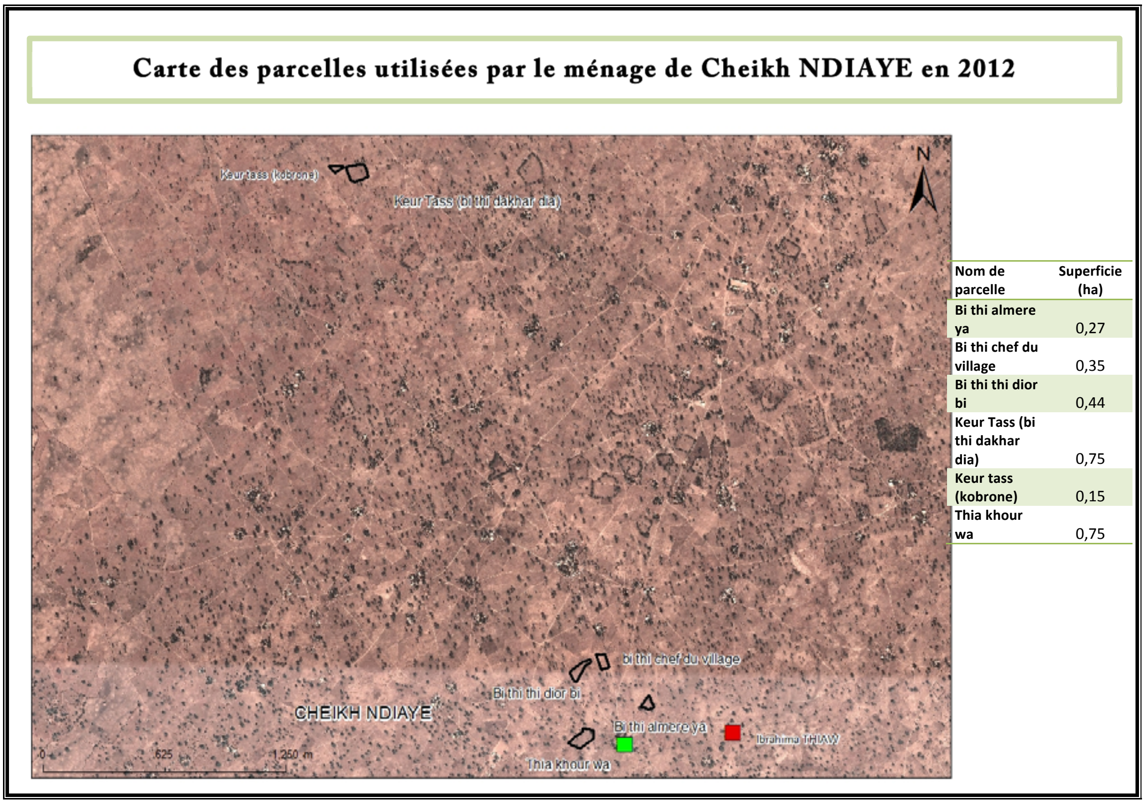
9.3.3 What could be? (1h)

OPERA method is used to broach «What could be?» topic. The 15 members groups from participative mapping are reassembled. Each group works on soil fertility improvement possibilities for their terroir. To generate original ideas if imagined improvement are limited to funding projects, the secondary question: «What improvements can be implemented without external funding or material brought? » is then asked.

9.3.4 Workshop conclusion

To conclude the workshop, villagers' point of view has been collected on the project (surveys, plots GPS mapping and participative workshop). This feedback is essential to improve the methodology selected for future studies, to better understand stakeholders' expectations and to underline their role in project's construction.

Two kinds of medium are left in the villages. The first one is individual file for each household. They present plots map following villagers request, the household nitrogen balance clarified with diagrams to facilitate their reading (see figure 15). The second medium type is two printed canvas. The first one measures 2.25m^2 and represents the plot scale nitrogen balance map. The second one is the terroir nitrogen balance in A2 format. Both canvas are deliberately given to the village headman or to Sassem public figure as a discussion tool with NGOs or public authorities since actors are results co-owners (Chambers 2006).



Nom de parcelle	Superficie (ha)
Bi thi almere ya	0,27
Bi thi chef du village	0,35
Bi thi thi dior bi	0,44
Keur Tass (bi thi dakhar dia)	0,75
Keur tass (kobrone)	0,15
Thia khour wa	0,75

Bilan azoté du ménage de Cheikh NDIAYE

L'azote est un des éléments nutritifs essentiels aux êtres vivants. Il est notamment particulièrement important dans la constitution des muscles.

Nitrogen role for humans and plant explanation

Il est présent dans de nombreux aliments, par exemple :

Aliment	Teneur en azote (N)
Mil	1,8kg N par barigot
Sorgho	1,5kg N par barigot
Arachide	5,6kg N par barigot
Niébé	4kg N par barigot
Maïs	1,5kg N par barigot
Viande	2kg N pour 10kg
Poisson	0,3kg N pour 10kg

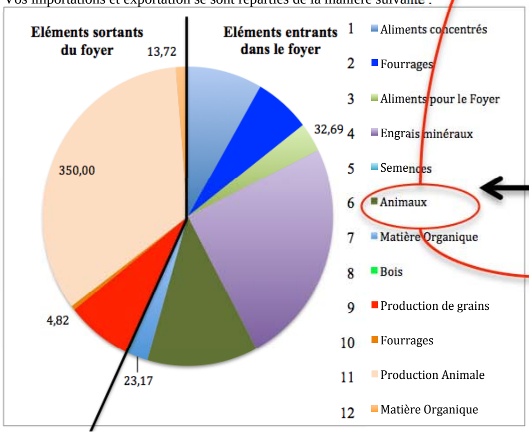
Nitrogen rates examples in food

Il est non seulement nécessaire aux humains mais aussi aux plantes puisqu'il favorise leur croissance. Vous l'apportez à vos champs sous forme de fumier, de déchets ménagers ou d'engrais.

Produit épandu	Teneur en azote (N)
Fumier pur	1,6kg d'N par charrette
Fumier pailleux	0,6kg par charrette
Déchets ménagers	0,02kg par bassin

Nitrogen rates examples in field inputs

A travers vos achats, vos ventes et vos dons vous importez et exportez de l'azote. Si l'on fait la différence entre l'ensemble de l'azote qui est entré et sorti de votre ménage, en 2012 vous avez importé 141kg d'azote (N).
Vos importations et exportation se sont réparties de la manière suivante :



Household nitrogen balance by category

- 1 : Les aliments concentrés sont par exemple le racal, le ripasse, le son de riz et le son de mil que vous avez achetés pour à vos animaux.
- 2 : Les fourrages sont la fâne d'arachide, la paille de mil et la fâne de niébé que vous achetez ou l'herbe que vous récoltez hors de vos parcelles en saison des pluies
- 3 : Les aliments pour le Foyer sont par exemple le riz, le mil, le maïs, la viande, le poisson que vous achetez pour nourrir votre famille
- 4 : Les engrais sont l'urée, l'engrais mil ou l'engrais arachide achetés sur les marchés
- 5 : Les semences sont uniquement les grains que vous avez achetés ou reçus pour semer vos champs
- 6 : Les animaux entrants sont les animaux que vous avez achetés ou reçus
- 7 : La matière organique entrante est le fumier que vous avez acheté, le parcage d'animaux de vos voisins sur vos parcelles, les résidus de culture que vos animaux ont prélevé lors de la vaine pâture
- 8 : Le bois représente les achats de charrettes de bois
- 9 : La production de grains représente la vente ou le don de vos récoltes
- 10 : Les fourrages sortants sont les ventes ou dons de fâne ou de paille ainsi que l'herbe qui a été collectée sur vos champs pour le bétail des voisins lors de la vaine pâture
- 11 : La production animale est la vente ou le don d'animaux ou de lait
- 12 : La matière organique sortante représente le parcage de vos animaux sur les parcelles de vos voisins, ou la divagation de vos animaux en vaine pâture sur les parcelles de vos voisins, ainsi que les résidus de culture qu'ont consommé le bétail des voisins sur vos champs

Category explanation

Diagram explaining the categories based on pictures taken

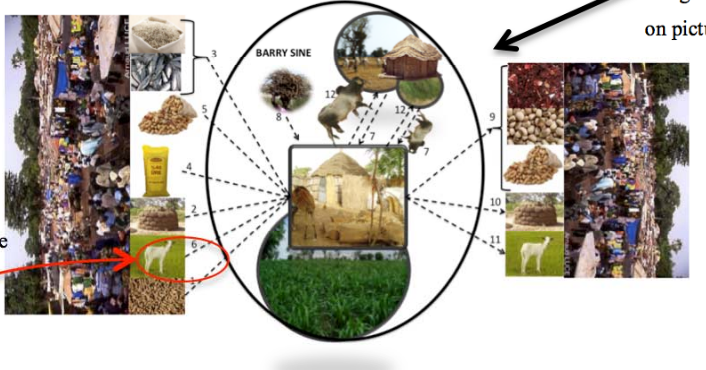


Figure 15: Individual file model transmitted to the interviewed at the end of the participative workshop

PART 3 : Results

After comparing villages structure, we will tackle biomass flows in order to illustrate the divergent agricultural practices to then describe multi-scale nitrogen balances and efficiencies and ending with terroirs perception and improvement dynamics in terms of fertility management.

10 Villages structure

10.1 Villages history

Barry Sine and Diohine developed in very distinct ways. Barry Sine was founded between 1898 and 1905 (Becker 1984). A discord between a Barry Ndondol inhabitant and the district chief led 30 household headmen to migrate on the Sine and Baol district frontier. The village would also have administrative grounds as these migrants had to pay their taxes twice, that is to say once for each district. Finally, the village was assigned to Sine zone what explains the current village name « Barry Sine » what means Sine's huts. Nevertheless, during the process, many villagers chose to go back in Baol area but continued to use Sine's water resources. Barry Sine's inhabitants rebelled but lost their fight and founder's lands access (Dia et al.1999).

Diohine has a longer history as it was established before the 20th century (Odru 2013) what impacted its structure development and Sassem neighbourhood.

10.2 Villages design

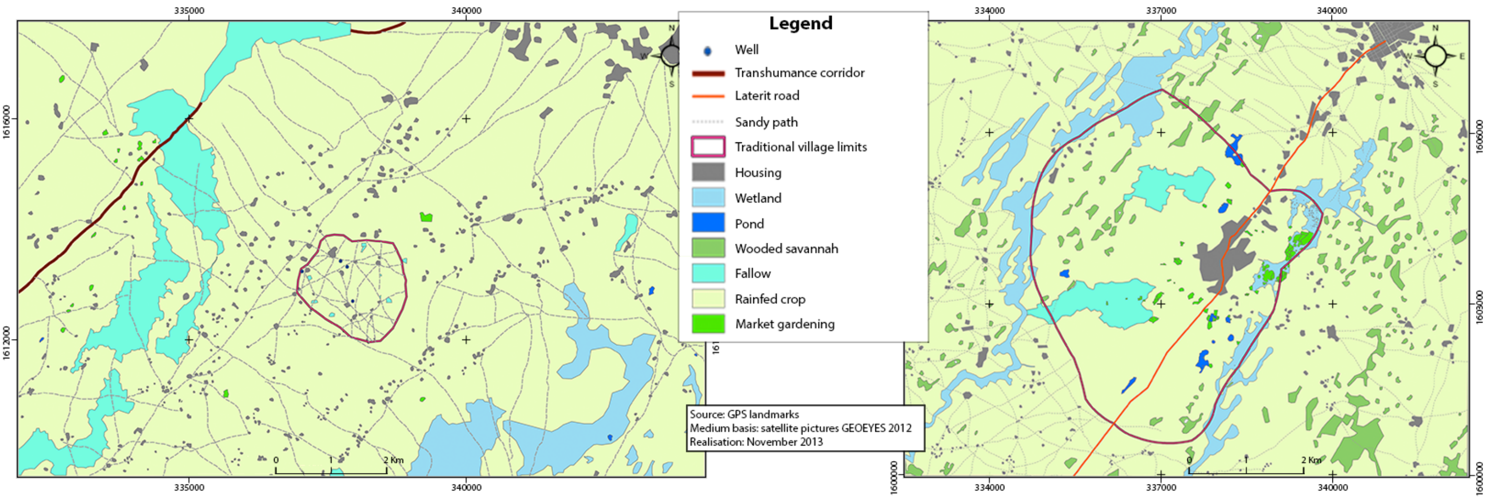


Figure 16: Barry Sine and Diohine agroecological zoning in 2013

Source : adapted from Ndiaye and Thiaw 2013

The figure 16 clearly demonstrates that in Barry Sine, the housing is parcelled out while Diohine is a "village centre" (Odru 2013) which housing are concentrated.

If housing area is closer in Diohine, compound gathering is stronger in Barry Sine what can facilitate commodity sharing, notably for agricultural machinery. Indeed both terroirs have 27 compounds, however, Sassem take a census of 44 households for 73 in Barry Sine with compounds that includes a larger number of households (7 and 9). Nevertheless, in both cases, single household compounds prevail.

In addition to housing structure, Diohine is also more coherent with a traditional village structuration around natural resources essentials for livestock maintenance on the terroir. Indeed Diohine is surrounded by backwater, source of fodder during the wet season that represents 67.2ha, that is to say 24.3% of Sassem neighbourhood's TTA (Total Terroir Area) while it is not included within Barry Sine UAL. Barry Sine does not comprise any pond or wooded savannah either.

In relation with its structure, terroir area is distributed differently in the villages.

10.3 Population and available surface area

Having higher numbers of household *per* compound, Barry Sine has human resources that provide a more intensive labour (3.2 inhabitants/ha for 1.8 in Sassem). This population density pushed Barry Sine's inhabitants to overstep traditional village limits for agricultural land use. Indeed, Becker in 1984 declared that *Ndiokh*'s bush plots were not cropped in Barry Sine (Becker 1984) while in 2012, a large surface area proportion is localised there. Even though they extended their UAL, Barry Sine's inhabitants consider less plots being "far" (bush fields) than Sassem's stakeholders[2] (see appendix 10).

Nevertheless, these population density differences did not seem to have impacted land rent as a similar rate was borrowed in both villages in 2012 (5.55% of the total UAL in Sassem for 5.06% in Barry Sine). Yet, available surface area and land tenure are decisive for agricultural practices. Indeed, if the user is not guaranteed to be allowed to rent the plot the following year, he will not apply organic matter (Wezel and Rath 2002), and surface area will impact crop diversity.

11 Practices and equipment

To describe agricultural biomass flows, we will follow livestock cycle starting from fodder production through land use distribution, looking at fattening practices and finally plots fertilisation considering other inputs that could have impacted the nitrogen balance.

11.1 Agricultural land use distribution

The higher population density in Barry Sine has negatively impacted fallow areas since it kept only a few individual one in 2012 while Sassem presents a large plot rate devoted to rainy season common grazing (48.9% of the UAL) (Odru 2013). Nevertheless it did not decreased cash crop area in favour of millet production as groundnut subsisted (30.3% of the UAL for 7.4% in Sassem (Odru 2013). Sassem developed other cash crops with market gardening absent from Barry Sine's UAL (see figure 17).

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[2] 53% considered as bush fields in Barry Sine for 83% in Sassem

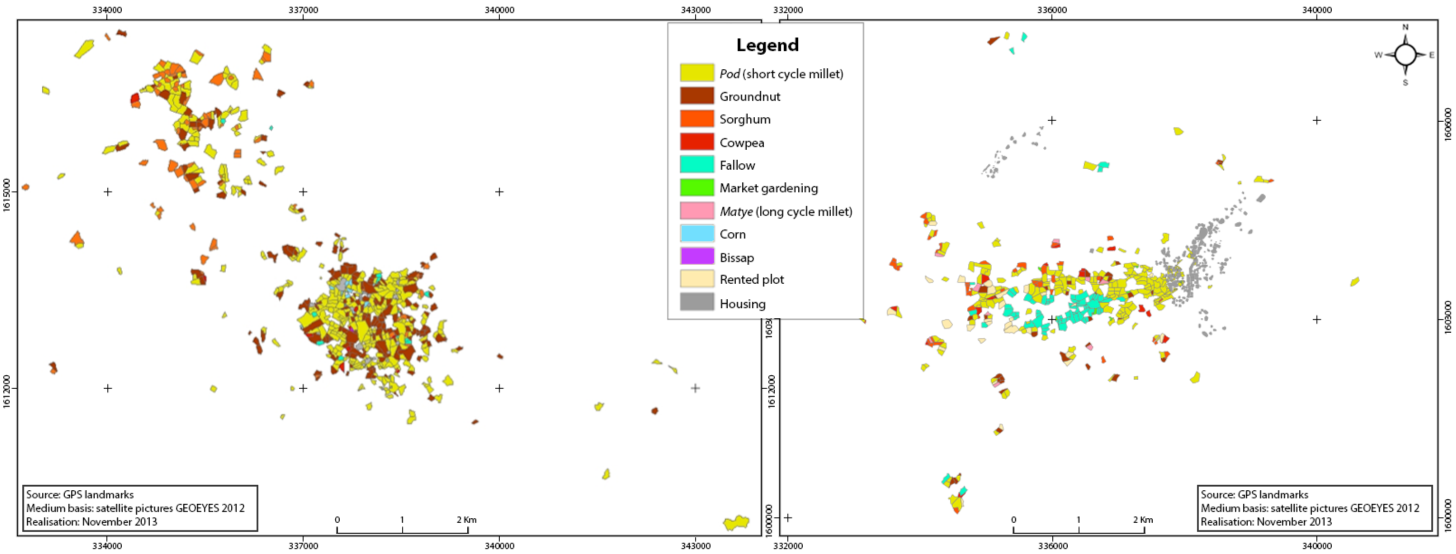

Figure 17: Agricultural land use distribution in Barry Sine and Sassem in 2012

Source: adapted from Ndiaye and Thiaw 2013

Intercropping was more complex in Sassem what favoured *matye* (long cycle millet) conservation on the terroir. Nevertheless cowpea intercropping was slightly higher in Barry Sine[3] what reveals a better woman access to lands (see appendix 11).

Land use distribution impacts livestock activity as fodder resources factor, for example, *Fabaceae* area and more especially groundnut area is quite a good indicator for livestock fattening development.

11.2 Livestock fattening

It is clear that bovine fattening did not reached the same degree in the villages. In Barry Sine, 64.4% of the households adopted this practice with in average 3 TLU per batch for 11.4% in Sassem with 1,5 TLU. In Barry Sine, this activity tends to be purely commercial as 4/5 of fattened TLU are bought exteriorly and fattened on a 6-7 months length while Sassem tends to valorise transhumant herd through finishing livestock fattening during 2 to 3 months (1/2 fattened TLU).

On the same model, ovine fattening was 10 times more adopted in Barry Sine[4]. It seems more intense in Barry Sine as fattening period for Tabaski celebration is reduced to 1-3 months (for 3.5-4.5 months in Sassem). Nevertheless, Barry Sine’s inhabitants also practice ovine fishing fattening[5], that is to say fattening lambs born of traditional ewes on a 7 to 8 months basis while Sassem’s inhabitants do not.

Goats were minor fattened animals as the activity was only represented in one household in each terroir.

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[3] 66% of the UAL was sowed with intercropping cowpea in Barry Sine for 53% in Sassem (Odru 2013)

[4] 54.8% of the households practiced ovine fattening in Barry Sine for 4.5% in Sassem

[5] 36% of the total fattened ovine TLU concern finishing ovine fattening in Barry Sine

Table 4: Livestock fattening feeding by animal category in Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

Type of livestock fattening	Fodder (kgDM/day/TLU)		Concentrates (kgDM/day/TLU)	
	Barry Sine	Sassem	Barry Sine	Sassem
Bovine fattening	4.07	10.76	2.38	2.52
Finishing bovine fattening	7.93	7.6	3.65	1.38
Ovine fattening	5.6	4.62	2.6	7.9
Finishing ovine fattening	2.21	-	1.41	-

« - » means this livestock fattening type is not practiced within the village
green: higher result for the input type considered
red: lower result for the input type considered

In terms of quantity, Barry Sine intensifies livestock farming in fattening-length logic. Indeed, bought bovine are fattened longer than bovines from transhumant herd which benefit from higher fodder and concentrate inputs. Equally for ovine, bought ovine fattened on a shorter period benefit from higher feed inputs while ovine from traditional herd, kept longer, are not always hobbled and can withdraw biomass during dry season common grazing.

Sassem does not follow the same logic and seems to favour larger animals for fodders (especially bought bovines as bovines from transhumant herds must have poorer body condition when returning from transhumance) and bought animals (especially ovine) for concentrates (see table 4).

In terms of quality, Barry Sine tends to depend more on terroir external inputs as a predominant part concentrates fattening rations is based on millet and rice bran while few was distributed in Sassem (Odru 2013).

Ovine seem to have a more diverse diet as in both villages cowpea hay and *Acacia albida* leaves and groundnut hay (for Barry Sine only) are saved for them.

After looking at livestock fattening practices, we can wonder how it impacted plots' fertilisation.

11.3 Fertilisation practices

11.3.1Manure

Manure obtained from livestock farming is stored and highly depends on farm equipment, such as cart, to be spread over the UAL (Dugué 2000).

Table 5: Farm machinery and organic fertilization comparison for Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

	Barry Sine	Sassem
Household owning a hoe (%)	84	89
Household owning a drilling machine (%)	71	57
Household owning a cart (%)	86	48
Household owning a horse or a donkey (%)	93	98
TLU.year/ha (total terroir UAL)	1.36	0.99
Plot that received organic matter (% total UAL)	30.5	23.7

green: higher result for the village in comparison with the second one
red: lower result for the village in comparison with the second one

Quite similar household proportion is equipped with hoes and draught animals (see table 5) while Barry Sine inhabitants are more equipped with drilling machines and carts. Combined with a higher livestock density, this results in a higher UAL proportion receiving organic inputs.

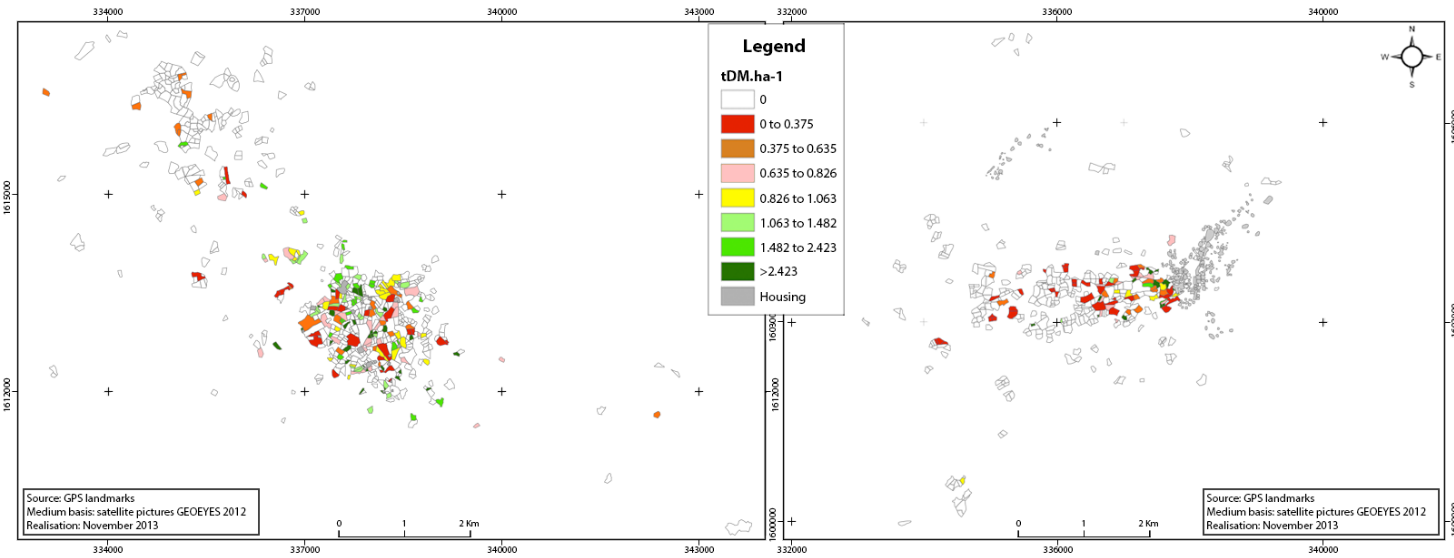

Figure 18: Manuring intensity localisation for Barry Sine and Sassem in 2012

Source : adapted from Ndiaye and Thiaw 2013

In both villages, organic fertilization favours hut plots rather than bush plots consistent with traditional patterns. Moreover, if we compare organic input doses, on figure 18 it appears that Barry Sine received higher quantities per surface unit[6] (1.62 tDM/ha in Barry Sine for 1.05 tDM/ha in Sassem).

If manure spread is a good indicator of fattening impact on soils' fertility, direct faeces and urine

[6] for the plots spread, significantly different for the all plots according to Student test and an error risk under 0.06%

deposition through night paddocking are more signs of traditional transhumant herds' impact.

11.3.2 Night paddocking

Night paddocking is not practiced a lot in both villages as a consequence of longer transhumance duration. Nevertheless Sassem neighbourhood could conserve more transhumant herds on the terroir during rainy season what provides its plots with 8% of total nitrogen inputs while Barry Sine did favoured their drop off during dry season common grazing representing 15% of plot total nitrogen inputs.

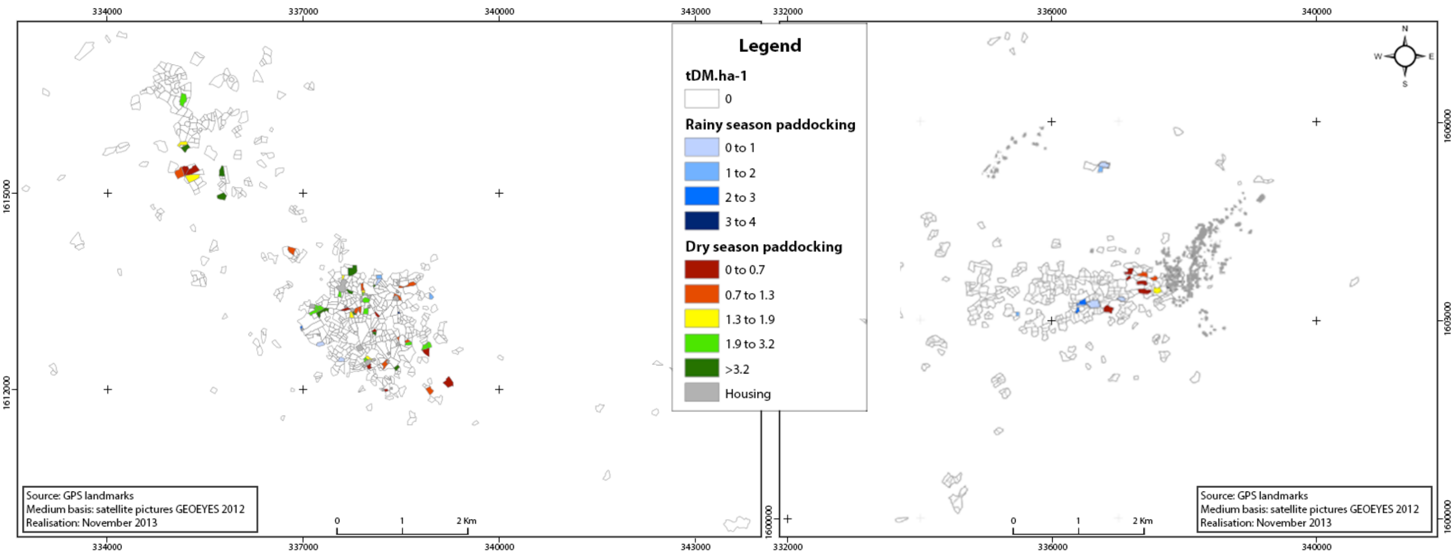

Figure 19: Night paddocking localisation for Barry Sine and Sassem in 2012

Source : adapted from Ndiaye and Thiaw 2013

As a consequence of land use distribution, rainy season night paddocking represents ten times higher plot portion in Sassem (2.7% of the total UAL in 2012 for 0.2% in Barry Sine). When practiced in the second village, it is more intensive thanks to TLU densities (1.75tDM/ha in average for 1.29 tDM/ha in Sassem) what can be confirmed on the figure 19 where only 3 of the 4 night rainy season night paddocking intensity category are represented in Sassem.

On the other hand, dry season night paddocking is 10 times more practiced in Barry Sine (38.6% of the total UAL for 3% in Sassem) and covers more agroecological zones as it is reserved for hut fields in Sassem. The average organic matter quantity dropped off on these plots is again higher for Barry with 2.57tDM/ha for 1.29tDM/ha in Sassem. Indeed, only 3 of the 5 dry season intensity categories are represented for Sassem on the figure 19.

11.3.3Mineral fertilizers

Finally, mineral fertilizers spread is not directly linked with livestock production but differs in the two terroirs and plays a preponderant role in both of them representing 26% of plot nitrogen inputs in Barry Sine for 18% in Sassem.

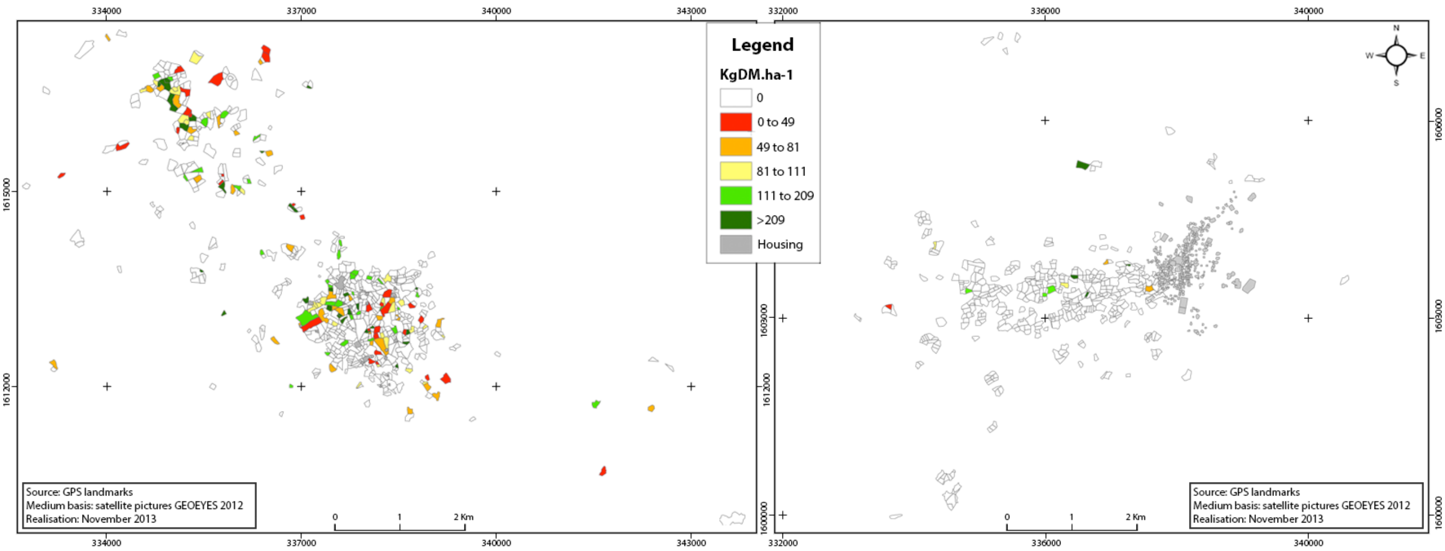

Figure 20: Mineral fertilizer spreading localisation for Barry Sine and Sassem in 2012

Source : adapted from Ndiaye and Thiaw 2013

Again, Barry Sine seems to manage more intensively its system with a wider mineral fertilizers use[7] (see figure 20) (applied on 27% of Barry Sine's UAL for 2.4% in Sassem). On the plots spread, on another hand, Sassem applied higher doses with 198kgRM/ha in average for 130kgRM /ha in Barry Sine.

After looking at principal inputs to fertilise, we will consider its impacts first in terms of yields and then in terms of nitrogen balances and efficiencies.

11.4 Yields

Table 6: Survey-based yields comparison for Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

Yields (kgRM /ha)	Barry Sine	Sassem	Difference
Main crop			
Millet (*pod*) in hut fields (ear)	795	1267	+59%
Millet (*pod*) in bush fields (ear)	657	577	-13%
Groundnut (pods)	421	444	+5%
Sorghum (ear)	779	479	-39%
Millet (*matye*) (ear)	-	755	-
Associated crops			
Millet (*pod*) (ear)	126	226	+79%
Sorghum (ear)	110	247	+124%
Cowpea (grain)	46	67	+45%
Bissap (flower)	11	22	+100%

« - » means the crop is not sowed within the village
green: higher result for the village in comparison with the second one
red: lower result for the village in comparison with the second one

[7] average quantities significantly different according to the Student test with an error risk under 0.01%

Barry Sine seems to favour bush fields (millet and sorghum) as its yields are improved there compared with Sassem's ones (see table 6), while Sassem demonstrates a better yield for hut field millet and favours *ndonate* (main crops association with millet, sorghum, groundnut). Indeed, Barry Sine simplified associations that are sometimes assimilated to volunteer crops what might explain yield differences.

Table 7: Total by-products production comparison divided by total UAL in Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

Total by-products production/ total UAL (kgDM/ha)	**Barry Sine**	**Sassem**
Millet straw	889	496
Sorghum straw	261	137
Groundnut hay	212	38
Cowpea hay	206	213

« - » means the byproduct is not produced within the village
green: higher result for the village in comparison with the second one
red: lower result for the village in comparison with the second one

If main crops yields are globally lower in Barry Sine, by-products quantities are by far higher (see table 7). We can therefore wonder if the practices and varieties were not selected in order to favour the fodder production

Table 8: Byproducts left on plots comparison in Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

By-products portion left on plots (%)	**Barry Sine**	**Sassem**
Millet straw	1	46
Sorghum straw	35	9
Groundnut hay	14	45
Cowpea hay	1	22

« - » means the byproduct is not produced within the village
green: higher result for the village in comparison with the second one
red: lower result for the village in comparison with the second one

Moreover, fodder production management differs as in Barry Sine, except in sorghum case, a larger by-products part is harvested, favouring livestock fattening practice, while Sassem inhabitants give more priority to common grazing and left higher biomass quantities on the plots (see table 8).

For Barry Sine practices that mostly impacted nitrogen balance were mineral fertilizers and dry season night paddocking while for Sassem, it was manure and household wastes[8].

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[8] according to the Pearson test

11.5 Nitrogen balances

11.5.1 Plot scale

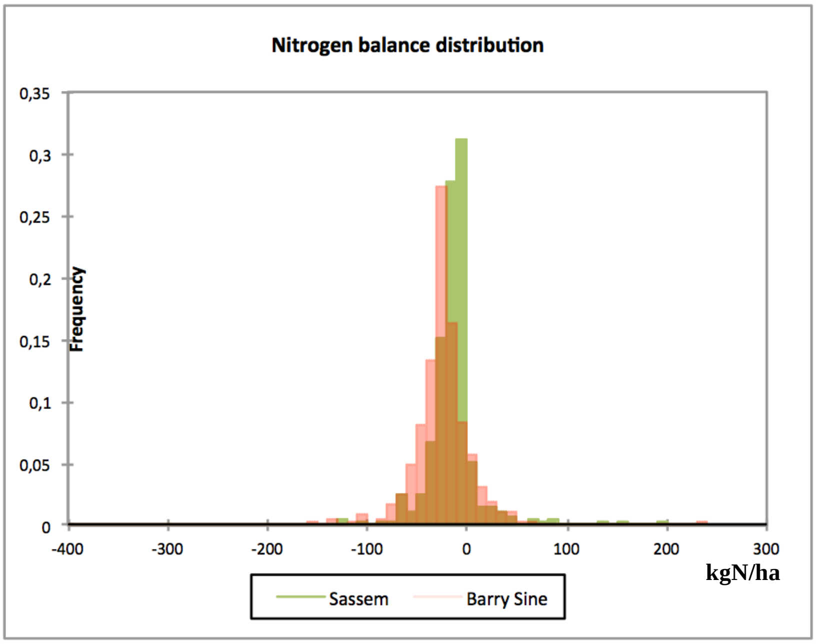

Figure 21: Nitrogen balance distribution for Barry Sine (in red) and Sassem (in green) in 2012

Source : adapted from Odru 2013 and personal 2013

Nitrogen balances are distributed symmetrically in both villages (see figure 21). Barry Sine's practices resulted in an average and median nitrogen balance slightly lower[9] (-24kgN/ha for Barry Sine and -13kg/ha for Sassem). Sassem's results are also more homogeneous as its variance is half Barry Sine's one[10].

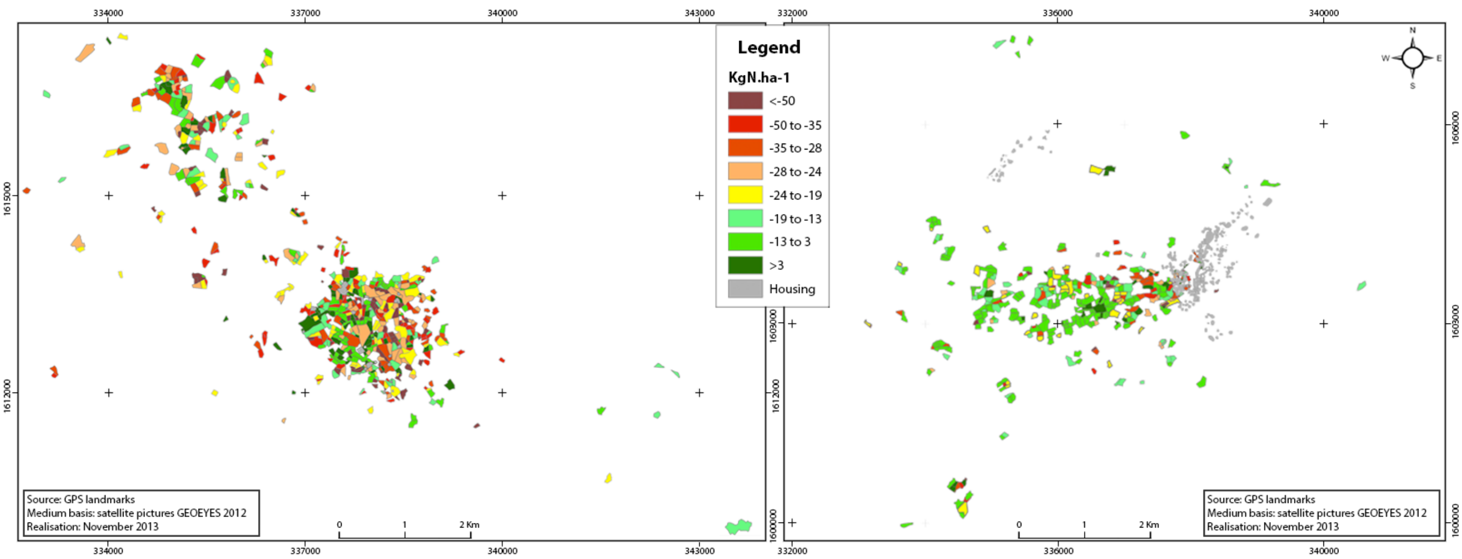

Figure 22: Nitrogen balance maps for Barry Sine and Sassem in 2012

Source : adapted from Ndiaye and Thiaw 2013

[9] according to the Student test and the Mood test with an error risk under 0.01%

[10] 721 variance in Sassem for 1503 in Barry Sine

Comparing villages' nitrogen spatial distribution (see figure 22) and according to an ANOVA test, nitrogen balance results do not depend on the ring considered (bush or hut fields). Now, for Barry Sine, Western plots and Northwest bush fields used by the highly populated Mbin Madiab and Sobna neighbourhood seem favoured. Thus, even if it was revealed not significant, we can wonder if Barry Sine's heterogeneous nitrogen balance can be attributed to housing dispersal and therefore less visible ring zoning.

Market gardening plots and plots within rainy season common grazing area, especially those combined with night paddocking have the best results[11]. Yet, these two land-uses were absent from Barry Sine's rotations during the 2010-2013 period.

These lower results, in addition to higher fodder exports, can also be attributed to groundnut fields' persistence, *Fabaceae* that fixes atmospheric nitrogen, which is not considered in visible balance. Inhabitants do not bring much input on groundnut fields as they reserve it for millet fields. Indeed, in appendix 12, we observe that groundnut and cowpea in both villages are among the crops with the lowest nitrogen balances. On the opposite, fallow, *pod* and sorghum were ranked in the same groups for both villages.

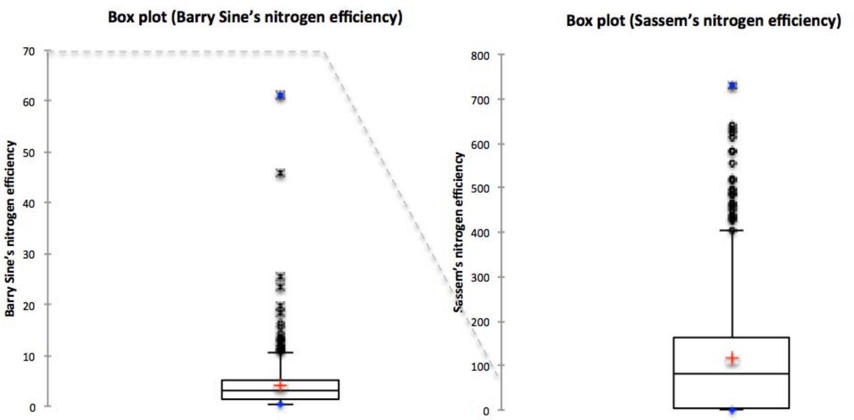

Figure 23: Nitrogen efficiency box plots for Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

It appears clearly on figure 23 that Sassem has higher nitrogen efficiency average (115 for 4 in Barry Sine), median[12] (81 for 3 in Barry Sine) and more spread out results[13].

In both villages, nitrogen efficiency depends on the ring considered, bush fields having significantly higher nitrogen efficiency than hut fields (according to the ANOVA test). In both cases, crops are ranked in the same order in relation with their nitrogen efficiency: cowpea, sorghum, *pod*, groundnut and fallow even if for Barry Sine, only cowpea was classified in higher nitrogen efficiency group (see appendix 13).

[11] according to the ANOVA test

[12] according to Student and Mood test with a risk under 0.01%

[13] 137 of standard deviation for 4 in Barry Sine

If we compare nitrogen balances slightly negative with nitrogen efficiency it seems that 2012's yields were partly based on soils nitrogen stocks or on nitrogen fixation through *Fabaceae*, widely used in the area as intercrop for cowpea or within the rotation for groundnut.

11.5.2Household scale

Agricultural practices led Barry Sine's households to be more dependent on imports as it globally presents higher nitrogen balance average (24kgN/ha for 7kgN/ha in Sassem) but less homogeneous with more scattered results[14] and slightly less efficient (0.92 for 1.43 in Sassem) homogenously[15].

Practices that mostly impacted household nitrogen balance concern livestock for Barry Sine, what traduces the importance of livestock fattening sector there and therefore the individual terroir management, and organic matter for Sassem[16], what traduces the importance of common grazing in this village and thus the communal terroir management. Seeds and wood were minor nitrogen flows in the villages.

Observing livestock importance on household nitrogen balances, households were divided into inferior, medium and superior TLU headcounts to compare livestock impact.

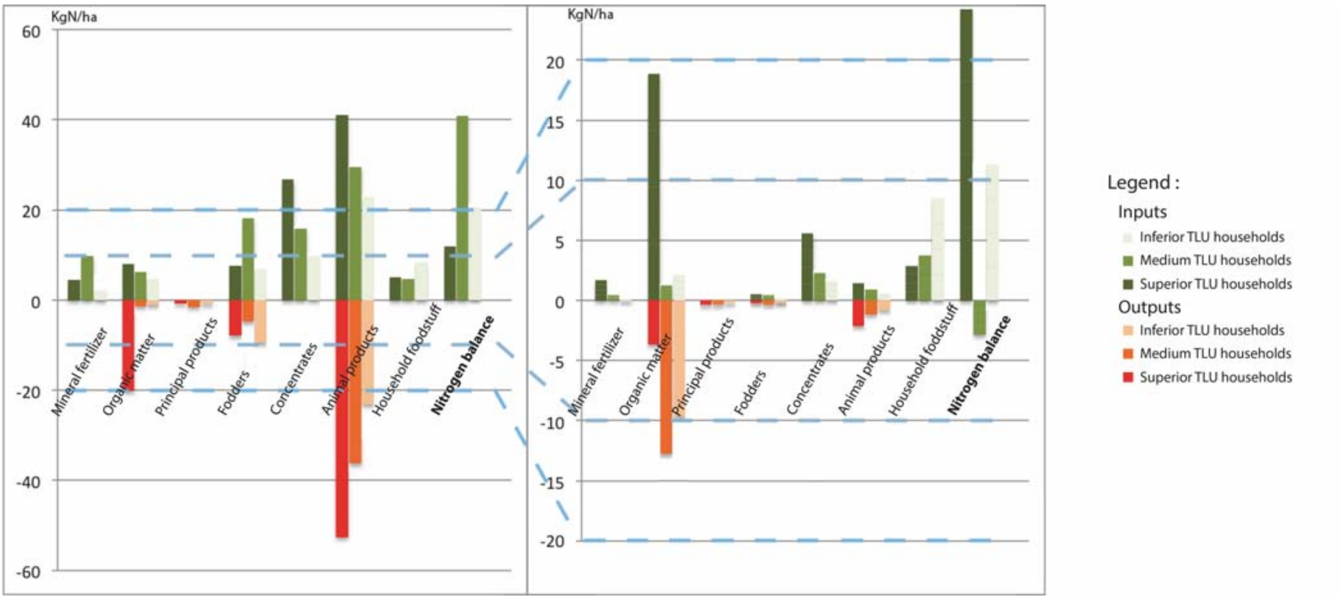

Figure 24: Average nitrogen balance distribution according to flow's nature and household classification related to TLU number for Barry Sine and Sassem in 2012

Source: adapted from Odru 2013 and personal 2013

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[14] 49.63kgN/ha of standard deviation in Barry Sine for 22.30kgN/ha in Sassem

[15] with a standard deviation equal to 0.84 in Barry Sine for 1.69 in Sassem

[16] taken as biomass withdrawal on others households' plots during common grazing for inputs, faeces and urine dropped off from other household herds for the outputs

While TLU headcounts relied on bought animals and increased concentrates imports (proportional on figure 24), fodders were not necessarily imported in Barry Sine.

In Barry Sine, contrarily to Sassem high TLU households have the lowest nitrogen balances and are more self-sufficient but also have the better production efficiency (1.10), while medium TLU household import the highest level of nitrogen and demonstrate the lowest production efficiency (0.6).

Sassem seems to favour self-sufficiency as the higher number of headcounts households have, the less they depend on imported foodstuff (inversely proportional on figure 24). Nitrogen balances and nitrogen efficiency here are indicators common grazing interactions and demonstrates that medium household tend to provide nitrogen to other households what results in a negative nitrogen balance and the highest nitrogen efficiency.

Table 9: Household structure comparison per TLU category for Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

		Inferior TLU	Medium TLU	Superior TLU
TLU.year	Barry Sine	1.82	5.04	15.29
	Sassem	1.07	2.49	11.47
Age of the head of the household	Barry Sine	47.04	55.55	59.79
	Sassem	52.57	53.93	58.73
Number of head of the household's wives	Barry Sine	1.00	1.45	1.96
	Sassem	0.71	0.87	1.13
Total population	Barry Sine	10.04	16.44	26.43
	Sassem	9.29	11.15	14.41
Number of drilling machine	Barry Sine	0.50	0.98	1.20
	Sassem	0.21	0.60	0.93
Number of occidental hoe	Barry Sine	0.63	1.10	0.84
	Sassem	0.07	0.27	0.27
Number of horse-drawn cart	Barry Sine	0.46	1.15	1.44
	Sassem	0.00	0.53	0.67
Number of donkey-drawn carts	Barry Sine	0.15	0.06	0.08
	Sassem	0.00	0.13	0.07
UAL	Barry Sine	2.56	5.55	8.28
	Sassem	3.17	4.88	5.86

green: higher result for this household TLU category
red: lower result for this household TLU category

Visually, we observe in table 9 that TLU headcounts is proportional to households' population, age of the head of the household, farm equipment and agricultural land area (redder column for low TLU households and greener for high TLU households).

11.5.3 Terroir scale

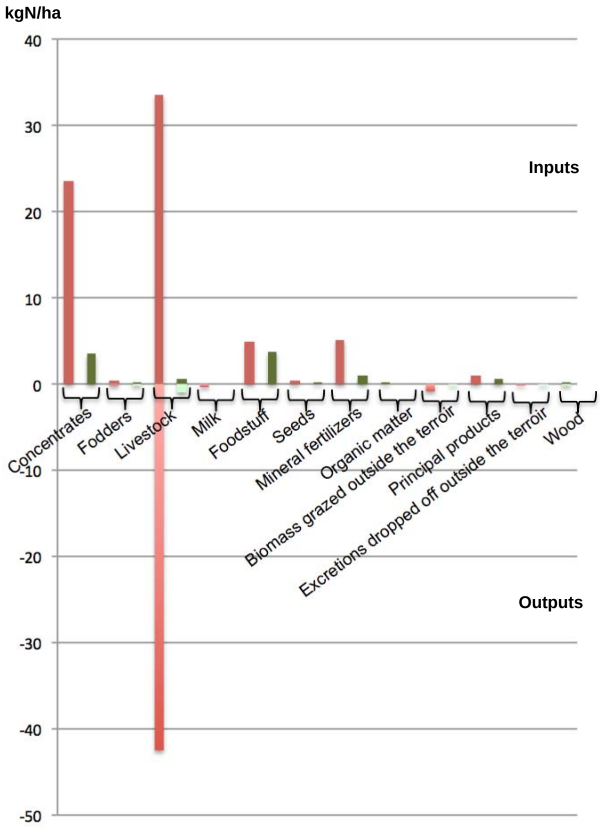


Figure 25: Nitrogen balance distribution divided by total UAL for Barry Sine (red) and Sassem (green) in 2012

Source : adapted from Odru 2013 and personal 2013

The figure 25 highlights system opening degree divergences. Indeed, Barry Sine's nitrogen imports and exports divided by the total UAL are clearly higher than Sassem's ones. Nevertheless, both terroirs are importing (24.2 kgN/ha in Barry for 8.7 kgN/ha in Sassem).

Leading imports are related to livestock (49% of the imports and 95% of the exports) and concentrates (34%). For Sassem, they are foodstuff (38%) and concentrates (35%) for the inputs and livestock for the exports (82%).

Even though both nitrogen efficiencies are under 1, Barry Sine 's one is 5 times higher than Sassem's one (0.65 for 0.12).

After analysing "What is" through survey results, we will tackle context perception from stakeholders point of view and "What could be" in terms of fertility management improvements.

12 Principal workshop results

12.1 What is?

12.1.1Available resources

The first exercise of the workshop consisted in listing terroir fertility components. The four groups (Barry Sine's men, Sassem's men, Barry Sine's women, Sassem's women) cited mineral fertilizers and manure (see figure 26).

Sassem's men quoted in addition to Barry Sine men's the common household waste pile but did not mentioned transhumant herd, rotations and farm machinery for this question.

Sassem's women cited fallow, chicken, night paddocking and trees in addition to Barry Sine's women.

For Sassem, women quoted chicken, fish scales in addition to men but did not mentioned the common household waste pile.

For Barry Sine, men cited rotations, farm machinery, trees, crop residues, night paddocking, fallow and transhumant herd in addition to women. However, they did not mention household wastes.

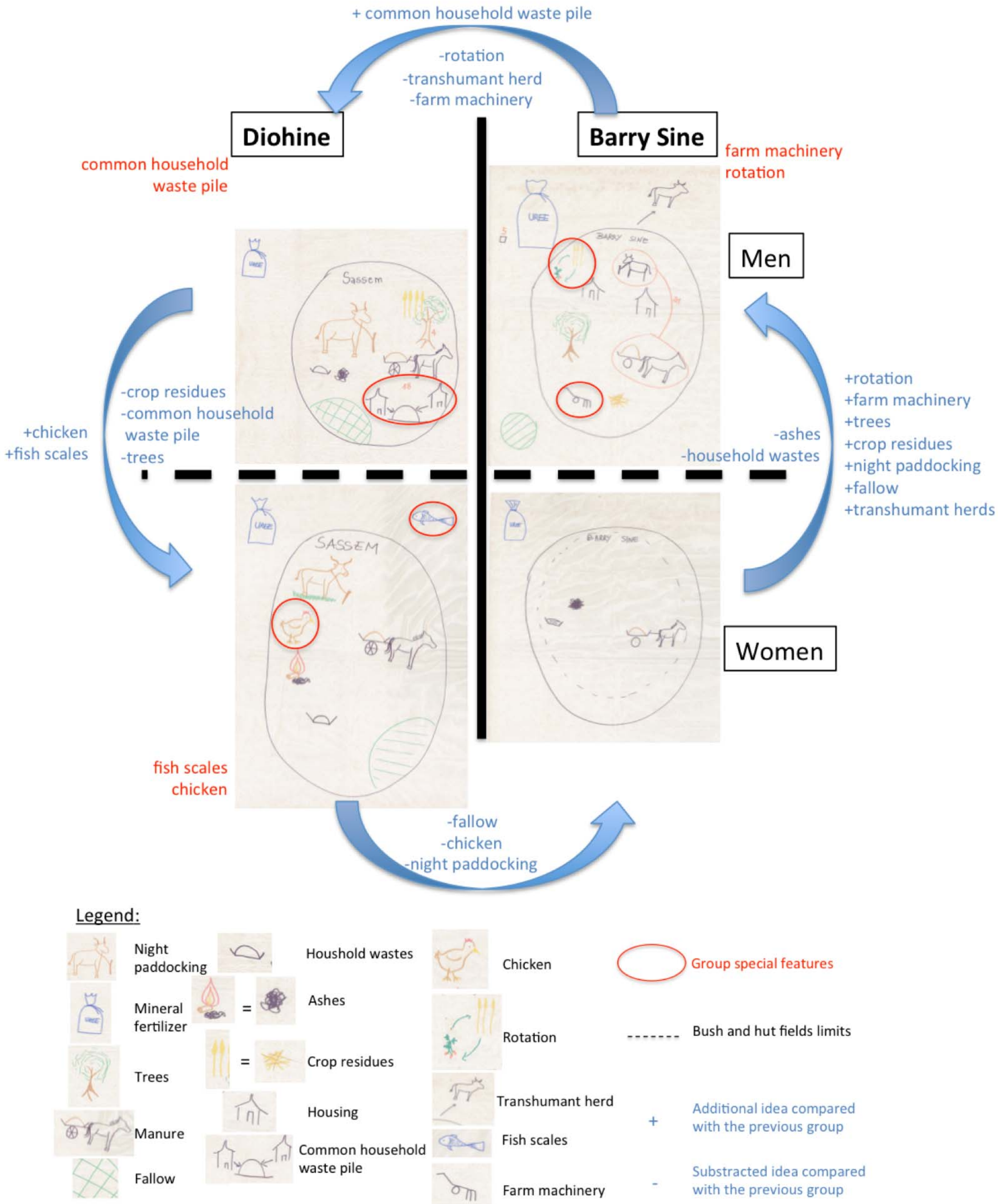


Figure 26: Resources enhancing terroir's fertility comparison for Sassem and Barry Sine and by gender listed during the participative workshop in 2013

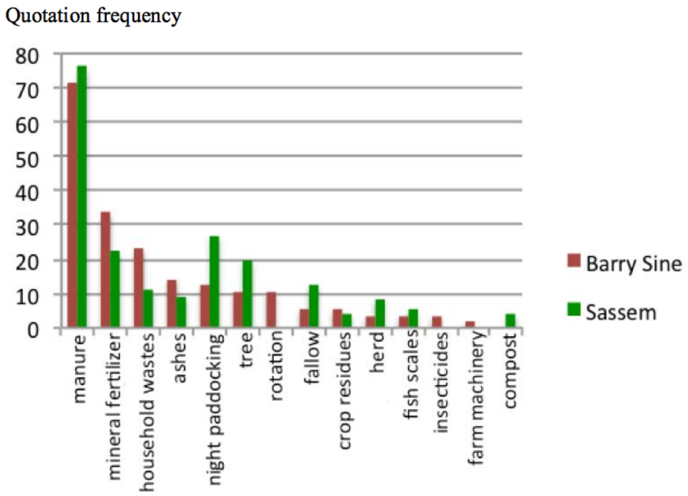


Figure 27: Resource quotation frequency comparison by village during the participative workshop in Barry Sine and Sassem in 2013

Once again, the most quoted terroir components in terms of fertility are manure and mineral fertilizers. In Barry Sine, a stronger emphasis was observed on mineral fertilizers, household wastes, ashes, rotations, crop residues, insecticides and farm machinery. In Sassem, manure, night paddocking, trees, fallow, transhumant herds, fish scales and compost were more quoted than for Barry Sine (see figure 27).

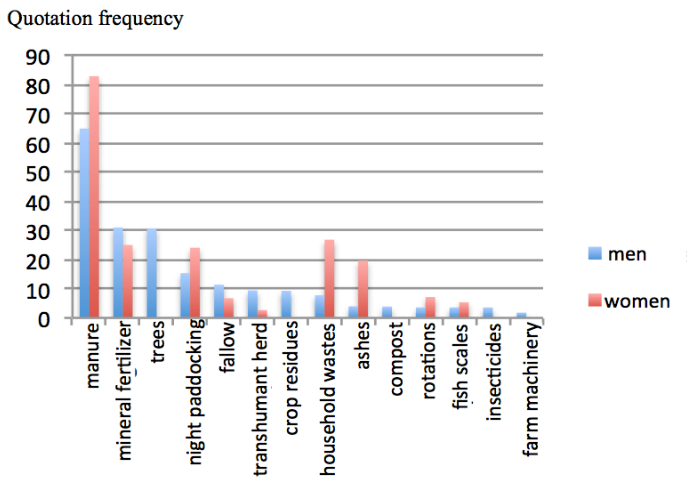


Figure 28: Resources quotation frequency comparison by gender for during Barry Sine and Sassem workshops in 2013

Globally, men highlighted mineral fertilizers, trees and crop residues more than women while women insisted more on manure, night paddocking, household wastes and ashes (see figure 28).

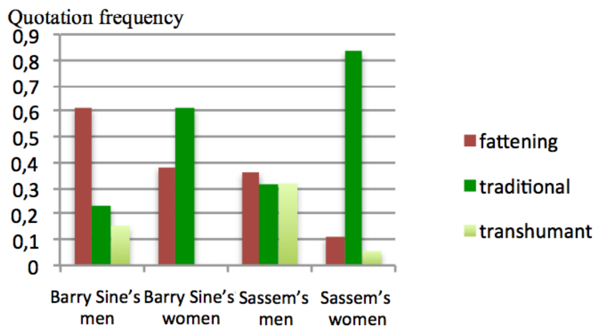


Figure 29: Livestock management quotation frequency comparison by gender and village during the workshops in Barry Sine and Sassem 2013

In Barry Sine, it seems that men insisted on livestock fattening. Women cited traditional livestock management rather than transhumant herd management (see figure 29).

After looking at the perceived terroir resources, we will analyse how villagers consider their impact on soils' fertility through spatial fertility distribution.

12.1.2Spatial fertility distribution

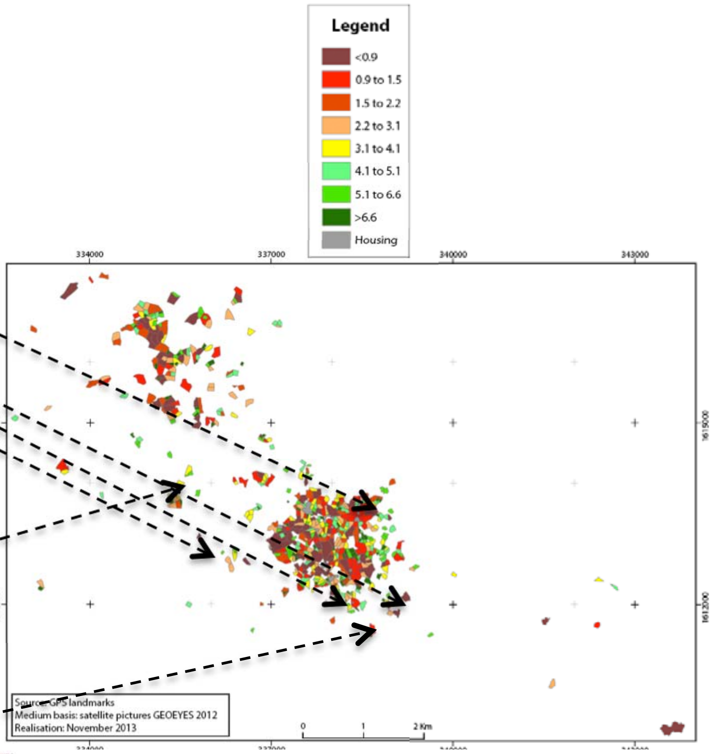


Figure 30: Nitrogen efficiency map for Barry Sine in 2012

Source : adapted from Ndiaye and Thiaw 2013

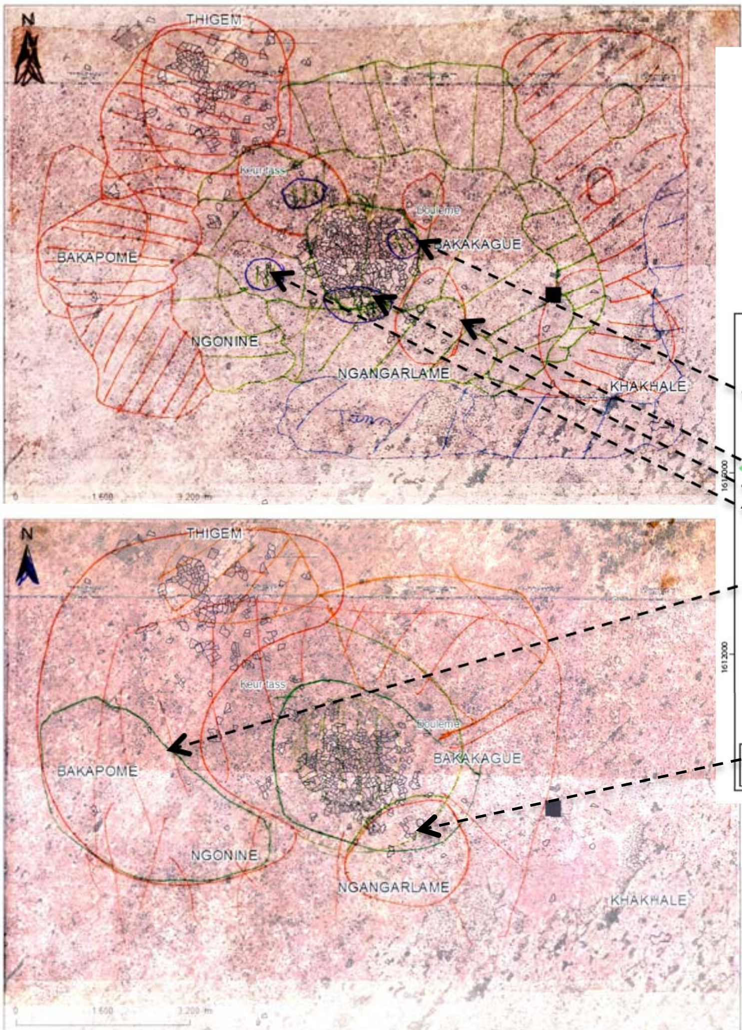


Figure 31: Terroir fertility zoning identified during Barry Sine’s workshop in 2013 (men: upper map, women: bottom map, in red: less fertile areas, in green: more fertile areas)

Barry Sine inhabitants agreed that closest plots from the housing are more fertile. They explain this difference by a higher intensification in this area, household waste spreading and *Ndior* (or *Mbou*) soil’s nature within the traditional village limits.

If we compare fertility maps drawn by the stakeholders superimposition with the nitrogen efficiency map which can be described here as soil’s reaction to inputs, we can highlight similarities. Men identified more fertile areas within village traditional limits. Men and women perceived Ngangarlame area (South of village traditional limits) as less fertile area. Women said that Bakapome and Ngonine areas are more fertile as a night paddocking area.

On the other hand dissimilarities appear as for bush and hut fields’ perception. Indeed, villagers indicated to us that Tchiguem is less fertile than plots within the village traditional limits what does not appear on the nitrogen efficiency map where Tchiguem present high efficiency plots (see figures 30 and 31). It is even the reverse that was observed when applying an ANOVA test, The farer plots had higher nitrogen efficiency in 2012 (3.9 in average for bush plots, 2.7 for hut plots).

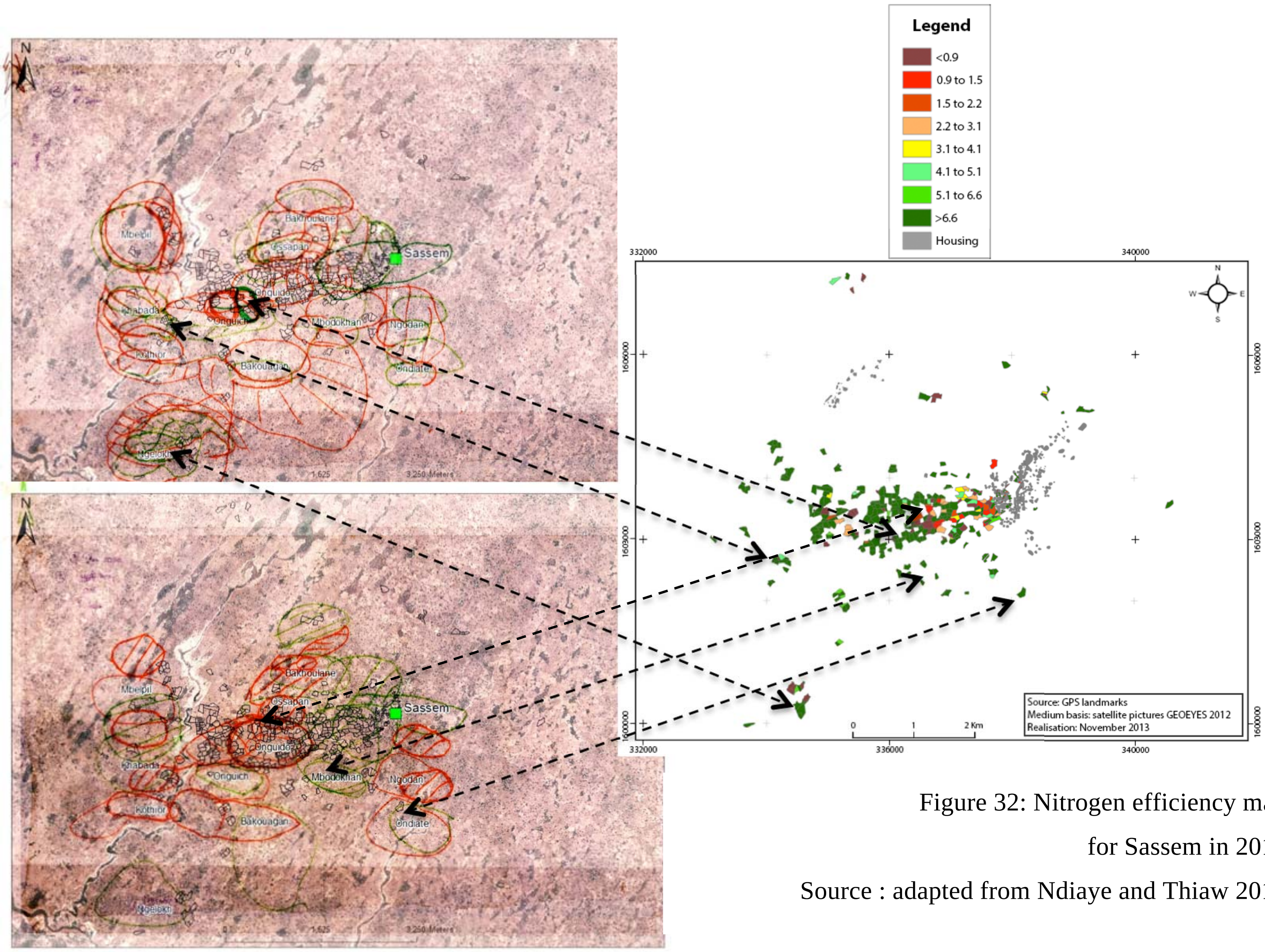


Figure 32: Nitrogen efficiency map for Sassem in 2012

Source : adapted from Ndiaye and Thiaw 2013

Figure 33: Terroir fertility zoning identified during Sassem's workshop in 2013 (men: upper map, women: bottom map, in red: less fertile areas, in green: more fertile areas)

For Sassem, villagers also agreed on attributing a higher fertility to hut plots rather than bush plots due to manure and free movements of animals. A group identified fallow areas as higher fertility plots.

Similarities with nitrogen efficiency map were for Ngelokh, Khabada and Onguich areas for men, Ondiate and Mbodokhan for women, all perceived as high fertility areas. Both genders said that Onguido was less fertile being a sandy soil and infested by *douroum* weed.

Major dissimilarity was also hut field perception. The actors thought they were more fertile while it is not visible on the nitrogen efficiency map either. Sassem inhabitants considered Kothior, Ossapan and Mbelpil as salted and less fertile but nitrogen efficiency seems to be high in these areas (see figures 32 and 33).

In both villages, the inhabitants said they apply manure in hut fields because they are more watched. Barry Sine inhabitants affirm that they spread mineral fertilizers on the all terroir while Sassem inhabitants said they are only spread on bush fields by lack of financial means.

12.1.3Terroir balances

In Barry Sine, men and women appear to be aware of their foodstuff import dependency as they said during the workshop that for cereals (millet and groundnut), purchases are higher than sales for the terroir scale. Nevertheless, this balance is slightly offset by fattened animal sales.

When we presented terroir nitrogen balance by category graphic, women noticed that cowpea and bissap sales portion was minimal in comparison with livestock fattening men activity (0.35% of terroir's nitrogen outputs for 95.56% in animal sales case) and therefore denounced activities in which they cannot take part.

When seeing Diohine's nitrogen balance by category graphic, Barry Sine's stakeholders noticed mineral fertilizers use and animal management differences between the villages. They observed more inputs for Barry Sine and thought it was a preferable situation.

In Sassem, men's point of view diverged from women's one as they consider selling more than buying. These sales would be justified by financial means during hunger gap to buy foodstuff. According to them, these needs would be increasing due to vaccination campaign that tend to raise children headcounts. Women, quite the opposite estimated that purchases are higher than sales since only bissap and cowpea are sold.

When seeing the terroir graphic that shown higher nitrogen inputs than outputs, men explained this difference by women's purchases. Women confirmed their own point of view commenting that production is not sufficient enough and that villagers favour home consumption and only sell as last resort.

Looking at Barry Sine's graphic, Sassem inhabitants noticed that the difference with Sassem was easily justifiable by Barry Sine's livestock fattening practice by means of rural exodus that funds this activity. Livestock fattening enable them to collect both financial means and manure. They also remarked that collective livestock fattening would be possible in Diohine as it is a large village. Women confirmed survey results that demonstrate a better land access for Barry Sine's women who would be freer to sow bissap and cowpea while Sassem's men do not welcome it.

After analysing "What is" we will tackle "What could be" from workshop results.

12.2 What could be?

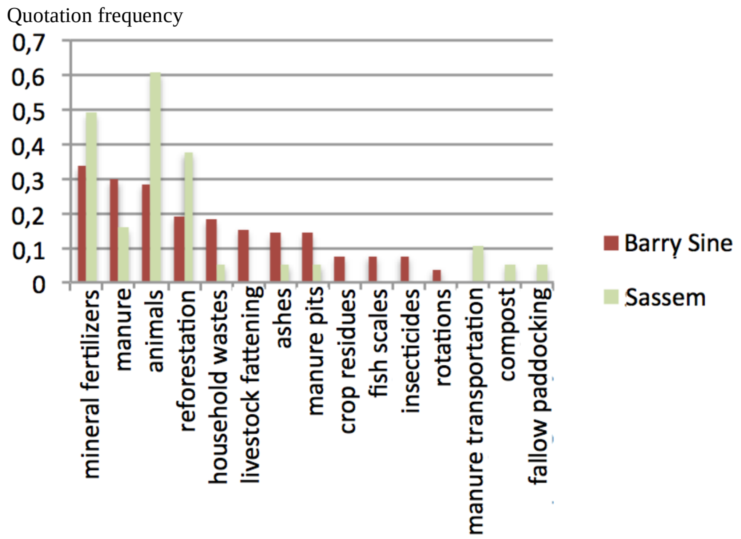


Figure 34: Improvements quotation comparison by village Barry Sine's and Sassem's workshop in 2013

In general, improvements focused on practices that already exist in both villages.

In Barry Sine, the improvements favoured were more numerous than in Sassem and gave priority to quantitative increase for mineral fertilizers, manure spread and for livestock headcounts. However, they insisted on the fact that increasing livestock headcounts through loans would enable them to buy less mineral fertilizers. Reforestation for them is a way to restore soil's fertility with vertical flows to counterbalance the small fallow surface area available due to population pressure booming. A quoted improvement that is already practiced was chapping and spreading crop residues. A women group proposed an innovation mentioning the possibility to develop manure pits to improve organic fertilizer quality watering it regularly, however, that would require their husbands' approval to fund materials such as concrete. A better access for women to livestock would enable them to fill the manure pit not only with household wastes but also with manure.

In Sassem, the inhabitants insisted on the necessity to increase livestock headcounts to counterbalance transhumance, on mineral fertilizers and tree density. The innovations they proposed were about manure pits and improving manure transport that is currently time-consuming and requires machinery that some of them do not own (see figure 34). They noticed that the low straw availability combined with tree density decrease due to population booming and therefore higher wood needs to make compound fences, roofs, and buildings. They questioned farm machinery impact on soils compared with the *iler* and highlighted the necessity to protect bush while using these tools. Trees are not only means to restore soils fertility but also favour plots water balance.

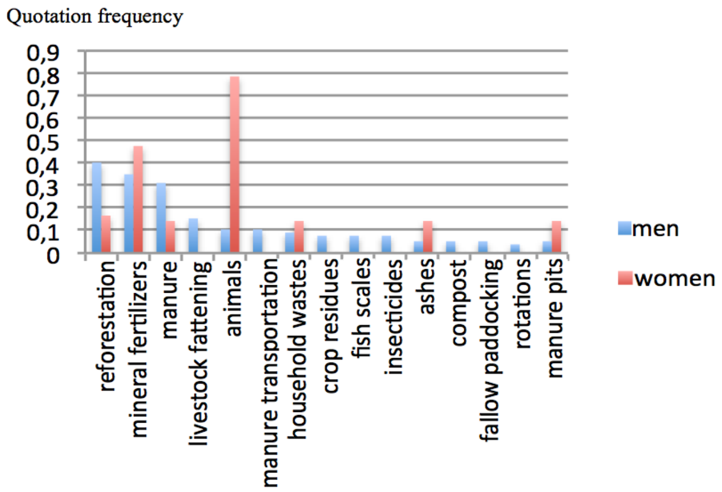


Figure 35: Quotation frequency comparison for improvements by gender during Barry Sine and Sassem workshops in 2013

Again, men showed a particular interest for trees, mineral fertilizers and manure. Contrary to women, they quoted livestock fattening, crop residues, fish scales, insecticides, compost, fallow paddocking and rotations. Women centred more on traditional livestock farming, and mineral fertilizers (see figure 35).

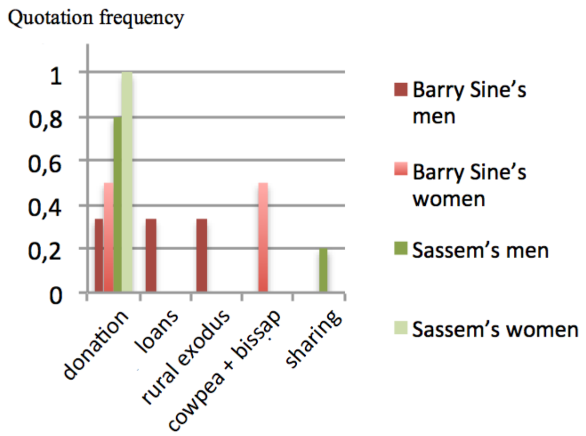


Figure 36: Quotation frequency funding source comparison to improve terroir's fertility by village and by gender during Barry Sine and Sassem workshop in 2013

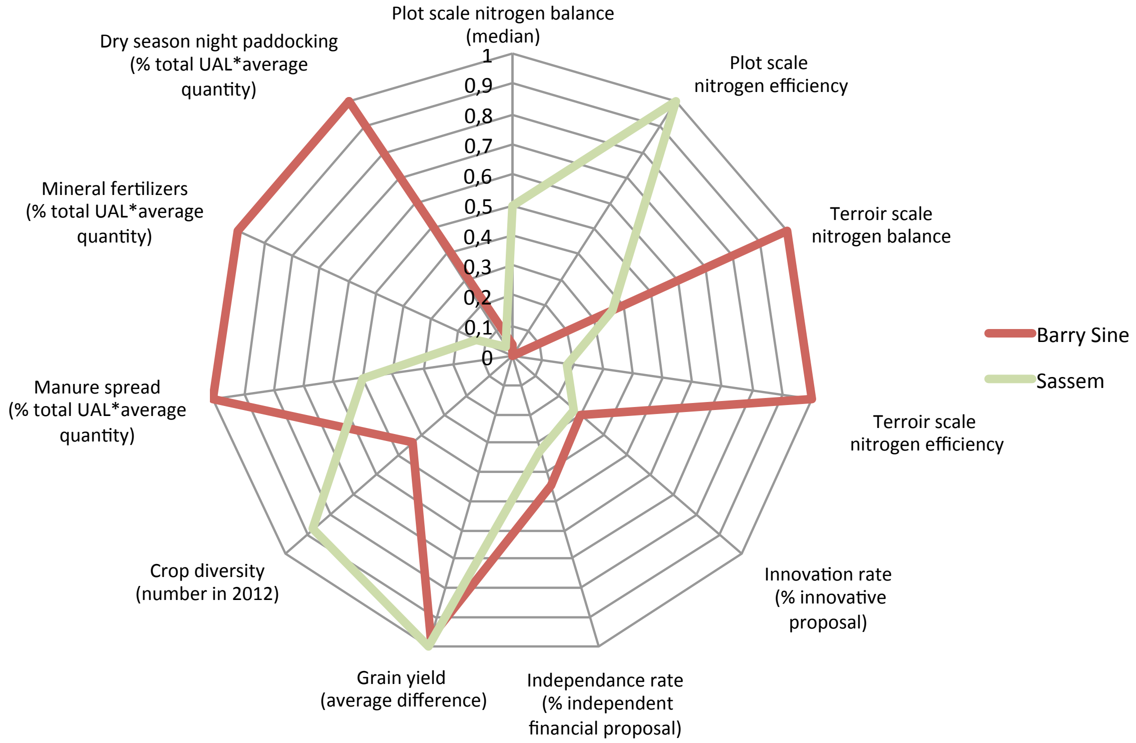
The four groups all cited donations through development projects or the State as funding sources cited. Barry Sine's men also discussed the possibility to fund the improvements with loans or rural exodus that represent for them the only alternative to external aid. Barry Sine's women mentioned cowpea and bissap surface area increase. Donations for them are essential to favour women access to livestock farming considering the few animals confided in the village. Sassem men discussed the possibility to collectively practice livestock fattening. Sassem women estimated that chicken and pig livestock farming increase would be possible without external funds but, on the other hand, concentrates purchase is still expensive and would require aids (see figure 36).

After analysing "What is?" through survey and workshop results and "What could be?" through workshop results, we will discuss the results described beforehand.

PART 4 : Discussion

13 In terms of results

13.1 Multiple parameters comparison



Village higher results=1 (except for nitrogen balance=0,5 as it was negative)

Village lower results= % of village higher results

Innovation and Independence rates for improvements are based on workshop

Innovation rate = proposals that differ from practices that already exist + livestock fattening preference compared with traditional and transhumant herds (in order to consider innovations already initiated)

Independence rate = % villages internal funding sources + % improvements declared possible without external funding

Crop diversity = village crop number in 2012 divided by total crop in both terroirs in 2012

Figure 37: Practices and vision village comparison for Barry Sine and Sassem in 2013

When comparing adopted strategies by each village, Sassem's strong point appears to be plot scale nitrogen balance and efficiency, rainy season night paddocking and crop diversity through market gardening. Barry Sine's strong points are terroir scale nitrogen balance and efficiency, dry season night paddocking, mineral fertilizers, manure, financial independency for improvements envisaged.

Terroir nitrogen balance should be put into perspective as it also demonstrates a lack of self-sufficiency.

13.2 Multi-scale analysis relevance

Table 10: Nitrogen balances and efficiency comparison at plot, household and terroir scales for Barry Sine and Sassem in 2012

Source : adapted from Odru 2013 and personal 2013

		Barry Sine		
Scale		**Plot**	**Household**	**Terroir**
Nitrogen balance (kg N/ha)	**Average**	-24.1	24.1	24.2
	Minimum	-397.7	-195.7	-
	Maximum	236.6	190.6	-
Nitrogen efficiency	**Average**	3.909	0.946	0.647
	Minimum	0.171	0.042	-
	Maximum	60.256	4.87	-
		Sassem		
Nitrogen balance (kg N/ha)	**Average**	-13.2	10.9	8.7
	Minimum	-125.4	-24	-
	Maximum	193.2	76.5	-
Nitrogen efficiency	**Average**	115.533	1.112	0.123
	Minimum	0	0.034	-
	Maximum	730.588	7.129	-

« - » means the calculation do not apply in this case
green: higher result for this scale and village
red: lower result for this this scale and village

Table 10 highlights multi-scale analysis relevance. Indeed, a large difference is observed between plot scale and household/terroir scales for nitrogen balance and efficiency. In Barry Sine, it seems that nitrogen major part is concentrated at terroir scale (looking at nitrogen balance) due to numerous external imports and a plot return that does not counterbalance plot's exports. Livestock fattening activity strongly impacts the results since the required imports for this practice do exceed exports, by-products such as manure seemed not to fill plants needs that had to draw on soils' reserves. In Sassem, nitrogen major part is concentrated at household scale, external imports are low and nitrogen balance is based on interhousehold flows from common grazing based on TLU household density.

13.3 Livestock fattening impact part in the results

From the results described beforehand, we observe dissimilarity with the scientific hypothesis that stated that livestock fattening should improve soil fertility. Actually, it was especially relevant to consider all terroir inputs and outputs as Barry Sine proved not to rely first on manure but on common grazing (thanks to higher transhumant TLU), on mineral fertilizers and add larger fodder yelds. On the opposite, Sassem relied mostly on manure what makes especially relevant their wish to develop common livestock fattening, nevertheless, fallow did impacted their nitrogen balance as rainy season common grazing was the third most important input.

However, Barry Sine had significantly more nitrogen plot inputs *per* hectare than Sassem[17] (23kgN/ha for 7kgN/ha in average) and especially manure flows. Its slightly lower nitrogen balance could be due to terroir soils' particularity or the methodology that does not consider vertical nitrogen flows (from nitrogen fixation by trees or *Fabaceae*). Even though nitrogen balance is not proved to be improved, Barry Sine does significantly have lower foodstuff imports[18] (2.237kgN/FU for 3.150kgN/FU for Sassem) beside the large plot area still devoted to groundnut instead of millet.

Livestock fattening (associated with rural exodus) had at least positive economical impacts since mineral fertilizer use and farm machinery, despite the more recent village foundation, indicates for Barry Sine a better financial household condition and social impacts with an increased self-sufficiency.

Most efficient plots were those drawing on soil's reserve especially for Sassem what cannot be sustain for long. Tree plantations are especially relevant improvements to develop as in Barry Sine's case, they had a positive impact on nitrogen efficiency.

13.4 Improvements feasibility

13.4.1Manure pits

Men or women cited manures pits as a possible improvement in both villages. They help improving manure quality and reduce loses. It also decreases expenses linked with mineral fertilizers and therefore improves household financial balance (Andrieu and Chia 2012) in compliance with Barry Sine stakeholders' dynamics.

Investments are quite feasible as it requires 3 concrete bags *per* manure pit and 90 bricks that are locally produced during dry season in Barry Sine (Fertipartenaires 2012).

Manure pits should be located 20m from housing but next to livestock fattening place not to contaminate water what is not currently coherent with the local system that includes livestock fattening activities within the compound. Also, manure should be turned and watered between October and November which are quite hardworking period with crop harvest (Fertipartenaires 2012).

In order to decrease moisture loses during the dry season, actors should be able to use animal feed leftovers (Fertipartenaires 2012).

Communication will be essential here to help women accessing this improvement they proposed. It would also require stronger partnerships with manure pit specialists such as

[17] according to a Student test with an error risk under 0.01%

[18] according to a Student test with a risk under 0.43%

Fertipartenaires team for the following steps.

13.4.2Reforestation

Reforestation has been strongly mentioned during the workshop especially for *Acacia albida*. Major challenges do not depend on tree implantation as the herds disperse the seeds and favour their germination by stomach acidity but strongly depends on seedlings protection from herds, farm machinery and fire (Kirmse and Norton 1984, CIRAD 1989). If this step is achieved, reforestation is effective as *Acacia albida* shown to be maintained if it survives its first dry season (CIRAD 1989).

To favour seedlings development and decrease fire impact, the area should be weeded on 1 to 2m in radius (Kirmse and Norton 1984).

Individuals should be well visible and fenced with local material such as thorny branches (see figure 38).

Figure 38: Protection of individual young seedlings using local materials

Source: Kirmse and Norton 1984

Strengthened partnerships with reforestation projects would be suitable in order to understand why previous reforestation projects failed, to promote stakeholders' training and eventually help funding this improvements.

13.4.3Common livestock fattening

Common livestock fattening could be suitable for Sassem as household interactions are strong in the village. Facilitation would be needed in order to insure system's fairness and organization such as fattening activities localisation, actor's financial participation and economic return.

14 In terms of methodology

Considering soils fertility differences observed between villagers perception and survey results the model chosen could be improved in two ways. First visible nitrogen balance could be artificially deepened evaluating humanure according to terroir population and housing distance. Secondly fertility assessment could be shifted from nitrogen visible balance to nitrogen balance including a coefficient linked with soil type (*Deck* or *Dior*) that could reflect lixiviation and including nitrogen fixation through *Fabaceae* what would better reflect areas sowed with groundnut and cowpea intercropping effects the year considered (not only rotation yields impact the next year).

Nitrogen is a good fertility indicator, nevertheless, fertility strongly depends on C/N ratio. Indeed, mineral fertilizers do impact the balance but do not reflect if soil's life is enhanced as microorganisms needs carbon to subsist and therefore as major agents of organic matter mineralisation. The study could therefore be improved considering both nitrogen and carbon balances.

This study focused on 2012's results. We should be aware that 2012 might have been a particular year and consecutive fertility balances should be implemented in order to confirm the results obtained.

Also, the study focused on two terroirs. If the nitrogen balance is positive, we can wonder which terroirs provided these nitrogen surpluses. Ferlo for example has a completely different agricultural system. We should remain that the results are not generalizable to the whole country and further comparison should be hold, for example with Ferlo or Casamance study sites.

General conclusion

This project's principal goal was to observe fertility impacts of system openness and agriculture intensification studying traditional system conservation or system based on new fertility management structured around livestock fattening. Facing new environmental constraints, a special emphasis was made on social dynamics to take into account global improvement relevancy.

The methodology used was based on systemic surveys in order to compare terroirs functioning and multi-scale nitrogen visible balances and efficiency in order to assess terroir's sustainability. Participative workshops helped in grasping terroir's perception and fertility management practices dynamics differentiating villages and genders applying a Soft System Methodology.

Barry Sine was strongly impacted by population growth (reducing the available area per inhabitant and increasing plot's dispersal) but does benefit from higher equipment levels. Around practices, Barry Sine developed cash generative activities (groundnut and livestock fattening). It actually manages its terroir more intensively (more organic and mineral fertilisation). It resulted in higher straw and bush field yields (millet and sorghum), household and terroir nitrogen balance and terroir nitrogen efficiency.

Sassem is an older village that maintained its natural resources diversity. It conserved traditional cropping system with fallow (basis of rainy season night paddocking), *matye*, *ndonate*[g] and developed cash crop through market gardening. These practices resulted in higher hut field yields, plot scale nitrogen balance and efficiency and household nitrogen efficiency.

Both terroirs demonstrated large flows from plots to household as cropping system is based on soil's reserve nitrogen depletion. Nitrogen was accumulated at household scale for Sassem because of large interhousehold interaction and at terroir scale for Barry Sine because of large external inputs for livestock fattening activities.

Livestock fattening impact on soil's fertility is difficult to assess because Barry Sine main inputs was not manure from fattening activities as the scientific hypothesis stated but common grazing dropped off thanks to larger transhumant herds TLU, and higher fodder production. Nevertheless, Barry Sine's inhabitant benefited from higher amounts of manure spread, better economical balance perceived through mineral fertilizer purchases and higher self-sufficiency despite the large area sowed for cash crops production.

Villager's perception of terroir fertility converged with survey's results around fallows positive effects but diverged around the closest plots fertility perceived as more fertile thanks to intensification, animals circulation and soils types while it presents lower nitrogen efficiency. Conscious about population growth and system openness, both terroirs inhabitants demonstrated a special interest for manure but also mineral fertilizers. Sassem had the particularity of focussing on common components and organic fertilisation while Barry Sine focused on rotations, equipment and mineral fertilizers. For genders distinction, specialisation activities impacted the concerns (women focussed on traditional livestock and household wastes while men focussed on night paddocking, mineral fertilizers, trees, crop residues, and livestock fattening for Barry Sine).

The improvements proposed were essentially quantitative increase of existing practices (mineral fertilizers, manure, livestock). Nevertheless, innovations were detected through reforestation and tree protection, manure pits, manure transport improvements and common livestock fattening for Sassem.

Improvements funding were essentially described through donations and loans, nevertheless, alternative financial means were considered. Rural exodus was described as a way to facilitate livestock purchase for men while women considered improving land access to crop cowpea and bissap as a possible monetary inflow to counterbalance their low livestock activity access.

The study revealed multi-scale analysis relevancy describing really different and complementary results for terroir management understanding. Methodological improvements could be developed around the model (type of balance and subsystems considered). Finally, to be able to generalise the results, other fertility assessment should be hold in the same sites to counterbalance particular year effect and in other sites to better reflect country’s agricultural management diversity.

Given the high population participation in research activities, in the future, the project should work on result communication to the households, NGOs and State representative that could fund some actor’s projects through micro-credits. System considered could be widen to study local associations, NGO’s and State interactions to be able to consider the relevant partnership that could help developing stakeholders’ projects.

About soil fertility management in Barry Sine manure pits could be developed trying to conserve a women part in it if a good communication around fertility improvement results is undertaken with men. For Sassem, efforts should focus on facilitating common livestock fattening. Finally, in both villages, advices could be given in order to facilitate trees protection.

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Glossary

- Common grazing: right to have their own animals grazing on other's plots in the absence of crops (Meyer 2013)
- *Dior*: sandy soils easy to work with but nutrient-poor usually cropped with groundnut and millet are selected for this type of soil (Dia et al. 1999, Ngom 2006)
- *Deck*: silty-clay loams, richer in nutrients than *Dior* soils but more cohesive in a dry state (Dia et al. 1999, Ngom 2006)
- *Deck-Dior*: sandy clay loams richer in organic matter and present an intermediate mineral composition. The crops found in these areas are similar to those of *Dior* soils (Dia et al. 1999, Ngom 2006).
- Hunger gap:

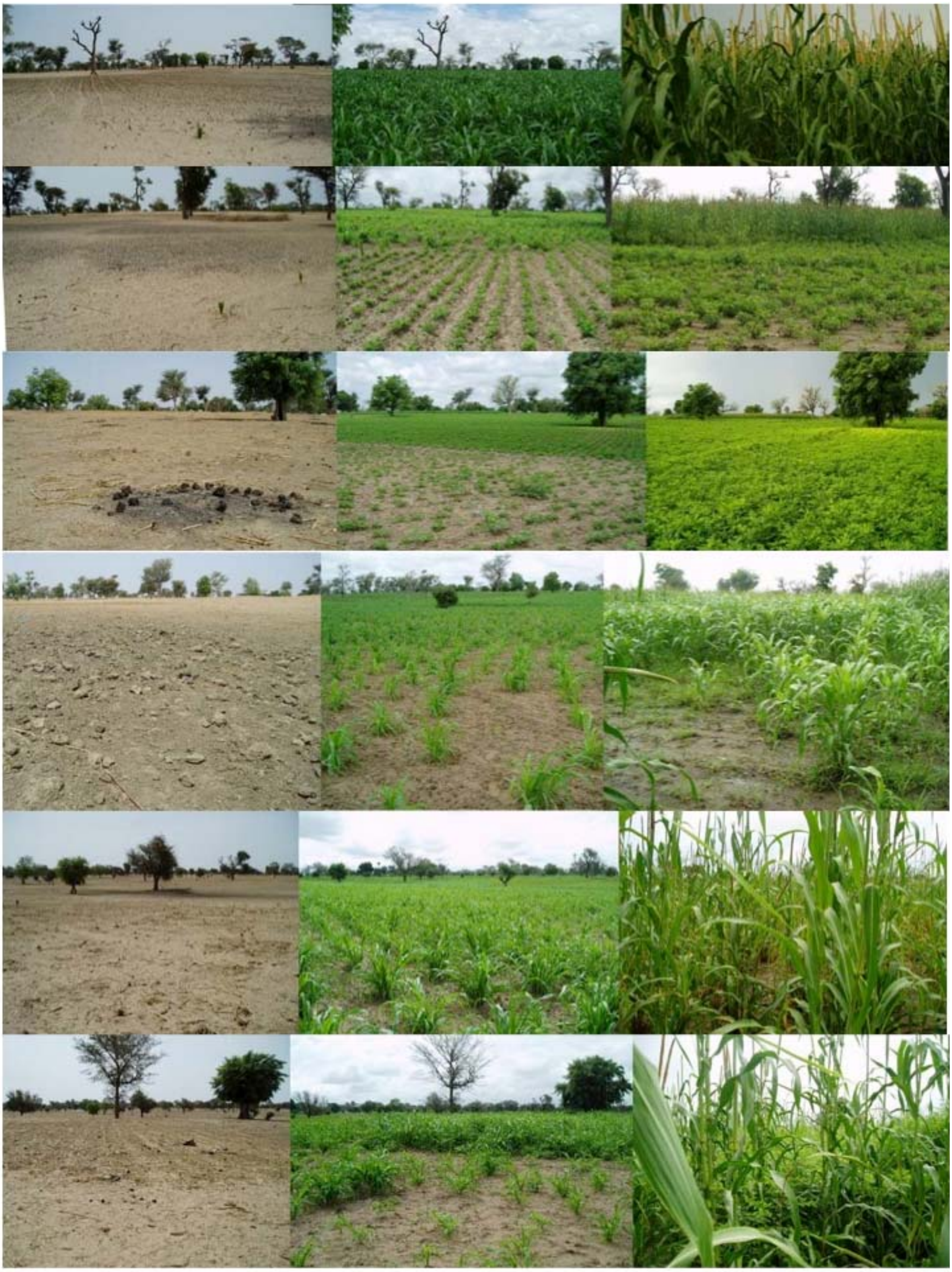
-stock exhaustion period before harvest

-fodder exhaustion between two grazing cycles, applied in this case to the end of the dry season before rainy season biomass new growth (Meyer 2013)

- Isohyet: a line drawn on a map connecting points that receive equal amounts of rainfall
- Livestock fattening: fattening practice for trade generally with animals hobbled and receiving large amounts of imported concentrates
- Night paddocking: tying livestock to stakes on a plot by night in order to fertilize it
- *Ndonate*: intercropping association of the main crop with millet, groundnut or sorghum
- *Pok*: « Social System in which a livestock farmer receive an animal from an owner, for example a goat. After a while, he only keeps part of the kids which survived, half of them for example » (Meyer 2013) the rest of the offspring and the adult are given back to the initial owner
- Soft System Methodology: systemic approach (rather than systematic) that transcribes system's complexity and is based on stakeholders participation and interest through action research (Flood 2000)
- Terroir: « cropped and farmed area by village community » (Rabot 1990)
- Traditional livestock: settled livestock but benefiting from common grazing and that do not receive high concentrates doses
- Transhumant livestock: livestock that seasonally migrates toward more fertile areas (Meyer 2013)

Appendixes

Appendix 1 : Wetness importance on vegetal cover evolution between the end of the dry season (May) rainy season beginning (July) and the middle of the rainy season (August) in 2013



Appendix 2 : Livestock fattening, tree fodder resources and fallow evolution

1. Livestock fattening practice evolution

1.1. Practice expansion

Livestock fattening evolution in Barry Sine soared up in 23 years. Indeed, there were about 22 bovines and 8 ovine fattened in 1990 within the village (Lericollais 1999). Nowadays, there are 211 bovines, 211 ovine and 4 goats fattened for trade purpose. In 1990, the village already based its adaptation strategy on livestock fattening as 3% of Ngayokhem's community bovines were fattened (Lericollais and Faye 1994) for 7% within Barry Sine (Lericollais 1999). The actors agreed to say that they have always seen livestock fattening in the village, the trend was stressed as by now, 31% of the bovines are fattened.

The practice is not undertaken by some isolated households as the IRD counted 78.3% of the compound that adopted this practice (Delaunay and Lalou 2012) and we did measure a slight increase reaching 81.5% of the compounds for bovine fattening. If investment costs are particularly high for bovine fattening, 70.4% of the compound adopted the alternative of fattening ovine what bring livestock fattening to a total 92.6% of the compound gaining access to the practice.

Adoption rates are not equally spread in the household of the compound as only 78.1% of the households fattens. About 54.8% of the households are practicing ovine fattening and invested in 3 rams in average, but annual headcounts can reach up to 21 rams. For 64.4% households that developed bovine fattening, the average headcounts is also about 3 oxen but reached 45 heads in some cases (see figure 1).

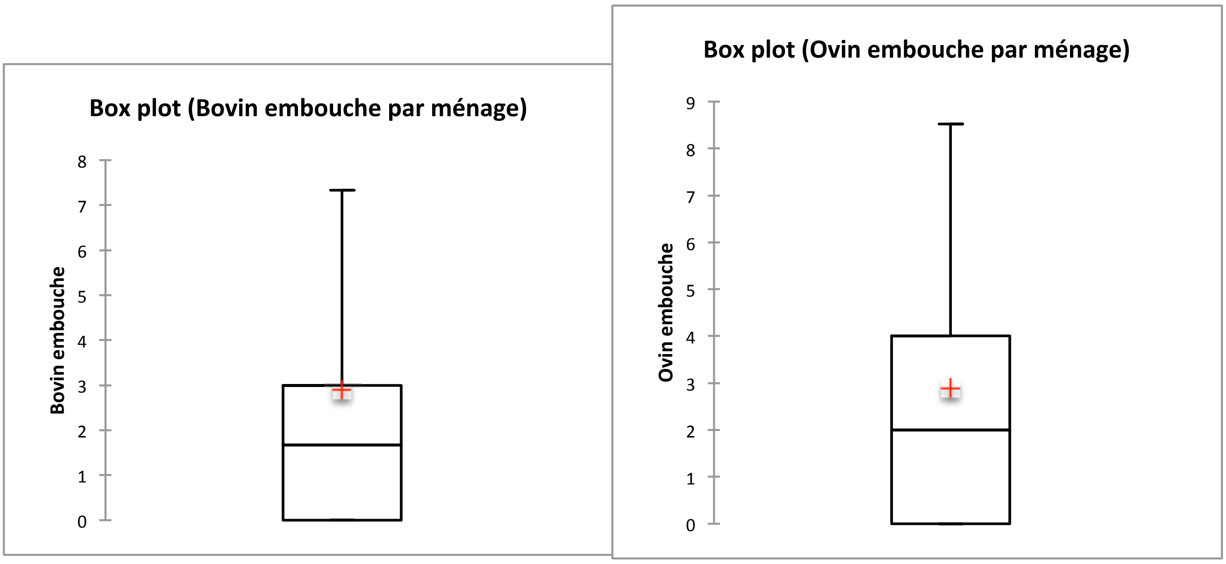


Figure 1: Bovine and ovine fattening practice in Barry Sine in 2012

1.2. From by-products valorisation to feeding

In early stages, livestock fattening was aiming at by-products valorisation (see table 1).

Table 1: Livestock fattening feeding in Sereer area from 1886 to 1999

		1986 (Faye, and Landais 1986)	1987 (Faye et al. 1987)	1988 (Lericollais 1988)	1990 (Garin et al. 1990)	1994 (Lericollais and Faye 1994)	1999 (Lericollais 1999)
Home consumption	Groundnut hay	x		x	x	x	x
	Cowpea hay			x	x	x	x
	Millet straw	x			x	x	
	Bush hay (post-cultural weeds or fallow herbs)	x		x	x		x
	Cereals bran	x	x				x
	Meal leftovers						x
External purchases	Groundnut hay	x		x	x	x	x
	Cowpea hay			x	x	x	x
	Groundnut cake	x				x	x
	Wheat bran	x				x	x
	Commercial concentrates	x				x	x
	Cotton seeds		x				

According to the table 1, livestock fattening also depended on imported products, notably for concentrates. This tendency is still relevant as only 4 fattened batches among 89 did not beneficiated from imported feed.

Table 2: Livestock fattening feeding per TLU and per day in Barry Sine in 2012

Fodder	Millet straw	Groundnut hay	Sorghum straw	Fresh cut grass	Dry cowpea hay	*Acacia albida* leaves	Corn stalk
KgDM/TLU/day	2.79	0.62	0.54	0.46	0.39	0.25	0.05
ration %	54.5	12.2	10.6	9.1	7.7	4.9	1.0

Concentrates	Millet bran	Rice bran	« Livestock feed »	Sorghum grains	Groundnut cakes	Cowpea grains	Cotton grains	*Acacia albida* fruits	Corn grains
KgRM/TLU/day	1.34	0.77	0.18	0.07	0.06	0.04	0.04	0.02	0.02
ration %	52.8	30.3	7.2	2.8	2.4	1.5	1.4	0.9	0.6

From surveys results, we could conclude that feeding ration did not changed a lot (see table 2), nevertheless some differences have been highlighted. Aerial fodders such as *Acacia albida* leaves are used, as well as corn stalk while bush hays are not part of the ration anymore.

The concentrates distributed do not include wheat bran anymore replaced by rice bran in Barry Sine. Cowpea grains, *Acacia albida* fruits and corn grains are used now but were not mentioned in the previous studies.

The practice has been slightly intensified. Indeed, in 1986, fattened livestock ration was about 7.5kg DM/TLU/day (Faye and Landais 1986). In 2013, in Barry Sine it reached about 7.65 kgDM/TLU/day.

In the past, fattened livestock was tied to a wooden post in the back of the compound yard (Faye and Landais 1986). In 2013 in Barry Sine, 12 batches among 89 were part of common grazing during the dry season (half ovine and half bovines). The rest of the batches stayed within the compound for their all stay.

2. Tree fodder resource evolution

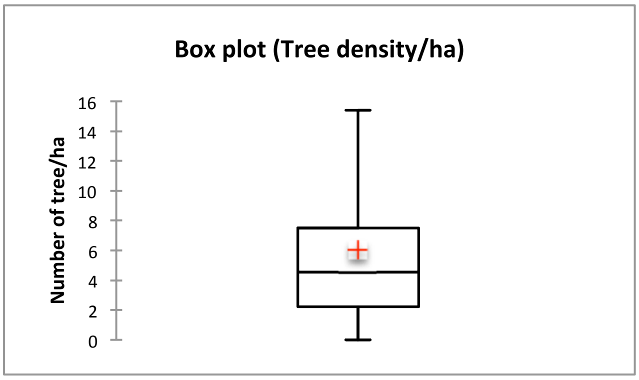


Figure 2:Tree density in Barry Sine terroir in 2013

Barry Sine tree density is 6 tree/ha in average but reach 73 trees/ha in some plots. Only 12% of the plots do not contain any trees in 2013. This density is far below 1966 ones, when Mr. Pélissier counted 20 to 30 trees per hectare in average (Lericollais 1999) (see figure 2). *Acacia albida* is clearly represented with 3.2 trees per hectare in average.

Table 3: Tree density evolution between 1965 and 2013

Sources : adapted from Lericollais 1999 and personal 2013

	Sob		**Barry Sine**
Year	**1965**	**1985**	**2013**
Acacia albida density/ha	6.90	4.55	2.57
Andansonia digitata density/ha	1.11	0.92	0.29
Anogeissus leiocarpus density/ha	0.33	0.26	0.50
Bauhinia rufescens density/ha	0.11	0.13	0.00
Celtis integrifolia density/ha	0.21	0.26	0.01
Diospyros mespiliformis density/ha	0.27	0.21	0.00
Gardenia ternifolia density/ha	0.11	0.09	0.00
Sclerocarya birrea density/ha	0.12	0.14	0.02
Tamarindus indica density/ha	0.15	0.12	0.06
Ziziphus mauritiana density/ha	0.13	0.15	0.10
Azadirachta indica density/ha	0.01	0.45	0.11

According to table 3, it appears that tree species are regressing from 1965 (in red in 2013). Only the *Anogeissus leiocarpus* increased.

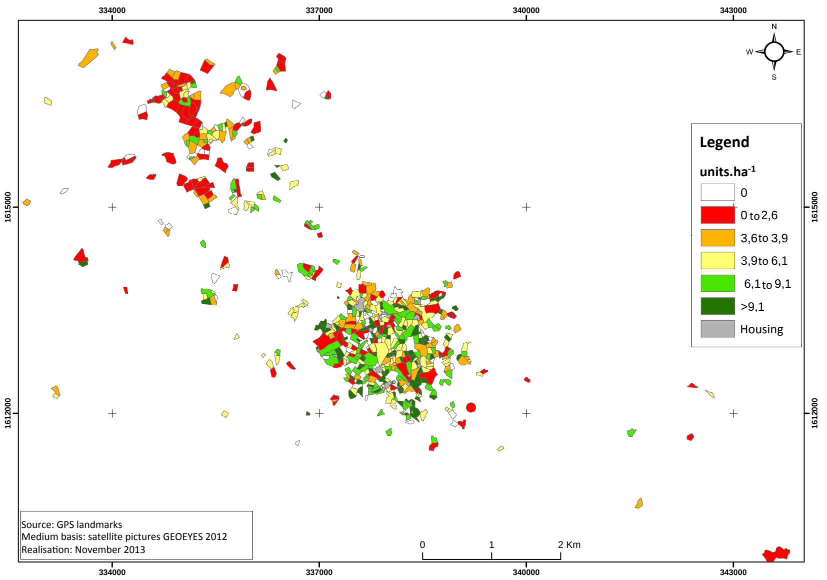


Figure 3: Tree density map in Barry Sine in 2013

Source : adapted from Ndiaye and Thiaw, 2013

Wood harvest as energy source for meal preparation takes place in bush plots what clearly appears on the figure 3 where low tree density is in the furthest plots.

3. Fallow regression

Lericollais described fallow regression in Sob village in particular where he took an inventory of 1/5 of the UAL under fallow system in 1960. In 1987 fallow was on 9.66% average of the UAL (2.33% in Sob, 8.26% in Ngayokhem and 18.39% in Kalom (Lericollais 1999).

Table 4: Fallow surface area evolution between 2010 and 2013 in Barry Sine

Year	2010	2011	2012	2013
Fallow surface area % UAL	0.95	4.08	1.18	4.18

For Barry Sine, according to the table 4, fallow extension among the UAL vary from 0.95 to 4.18ha. Fallow portion is thus inferior to the 1987 zone average. There is a slight increase between the years 2013/2012 compared to 2010/2011. Fallows seem to be favoured every two years.

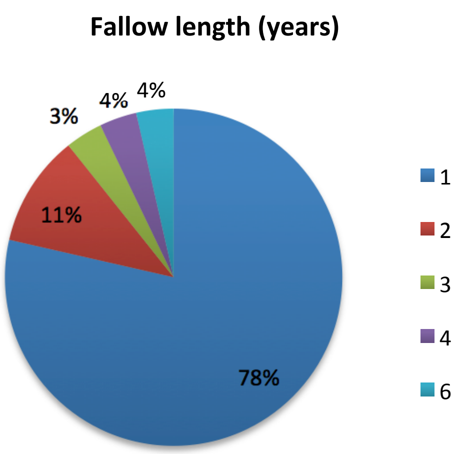


Figure 4: Fallow length in Barry Sine between 2010 and 2013

Indeed, according to figure 4, we observe that a large fallow proportion is part of rotation where they are only conserved for one year. Annual fallow was already practiced in the 80's (Faye et al. 1987) in the housing fringes, fitting into the post-colonial triennial rotation with millet and groundnut that succeeded to the millet/fallow biennial rotation (Guigou et al. 1998). Nonetheless, some plots can be kept with fallow for 6 years.

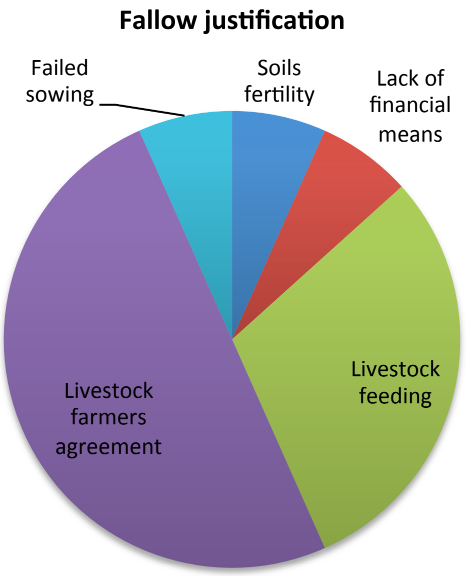


Figure 5: Reasons for fallow establishment in Barry Sine between 2010 and 2013

The figure 5 reveals that fallow conservation in Barry Sine is mainly due to livestock farmers' agreement gathering several villages. This area around Tchiguem is dominated by a fallow/sorghum rotation and is aiming at creating a continuous large surface area that can be grazed. According to the interviewed, the area is not used by Barry Sine's inhabitants to keep the livestock on the terroir during the rainy season because of its distance from the housing. Moreover, the fallow described in 2012 did not sustain any transhumant herds and are only used to feed traditional livestock.

Lericollais wrote that fallow conservation was mainly due to a lack of financial means to buy cereal seeds. Nowadays, it appears that in Barry Sine, accidental fallows are not predominant (Lericollais 1999).

Appendix 3 : Survey guide structure, Source Vigan, Odru and personal 2013

I. STRUCTURE

1) General data
2) Population
3) Equipment

II. CROP

1) Plots structure
2) Annual crops in 2012
3) Market gardening in 2012
4) Trees in 2012

III. LIVESTOCK

1) Bovines, ovine, goats
    1) Bovine milk production
    2) Batches movements (in 2012)
    3) Grazing, night paddocking and livestock run by batches
    4) Additional fodder and concentrates
2) Other livestock farming
    1) Batches movements (in 2012)
    2) Concentrates
    3) Additional fodder and concentrates
3) Animal confided

IV. EFFLUENTS STORAGE

V. HOUSEHOLD CONSUMPTION (in 2012)

1) Household basic commodity daily consumption
2) Products purchases (in 2012)

VI. HOUSEHOLD WASTES

VII. WOOD

Appendix 4 : FU and LU equivalence table according to the gender and the age, Source Busacker 1990

Category	**LU equivalence**	**FU equivalence**
Men		
>59 years old	1	1
15-59 years old	1	1
<15 years old	0.5	0.5
Women		
>59 years old	0	0
15-59 years old	1	0.2
<15 years old	0.5	0.5

Appendix 5 : TLU equivalence table by animal category, Source Meyer 2013

Animal category	**TLU equivalence**
Bovines	
Adult bovine (dairy cow, female>3 years old, male >2 years old)	1
Non-lacting dairy cow	0.8
Heifer from 2 to 3 years old	0.6
Heifer from 1 to 2 years old	0.5
Calf (< 1 years old)	0.4
Small ruminants	
Adult ovine or goat	0.2
Young ovine or goat	0.1
Others	
Equine	1.1
Asin	0.3
Avian	0.007

Appendix 6 : Input and output flows indicators related to common grazing

Indicator nature	Indicator value	Reference
Animal effluent		
Faeces dropped off (kg DM/day/TLU)	2.09	INRA 1989
Urine (kg DM/day/TLU)	3	Dongmo et al. 2009
Withdrawal		
Common grazing withdrawal (kg DM/TLU/day)	4.75	Diop et al. 2005
Millet straw withdrawal portion (%DM)	0.33	Dongmo et al. 2009
Sorghum straw withdrawal portion (%DM)	0.33	Dongmo et al. 2009
Corn stalk withdrawal portion (%DM)	0.67	Dongmo et al. 2009

Appendix 7 : Faeces nitrogen content kgN/kgDM according to the month, Source Manlay 2001

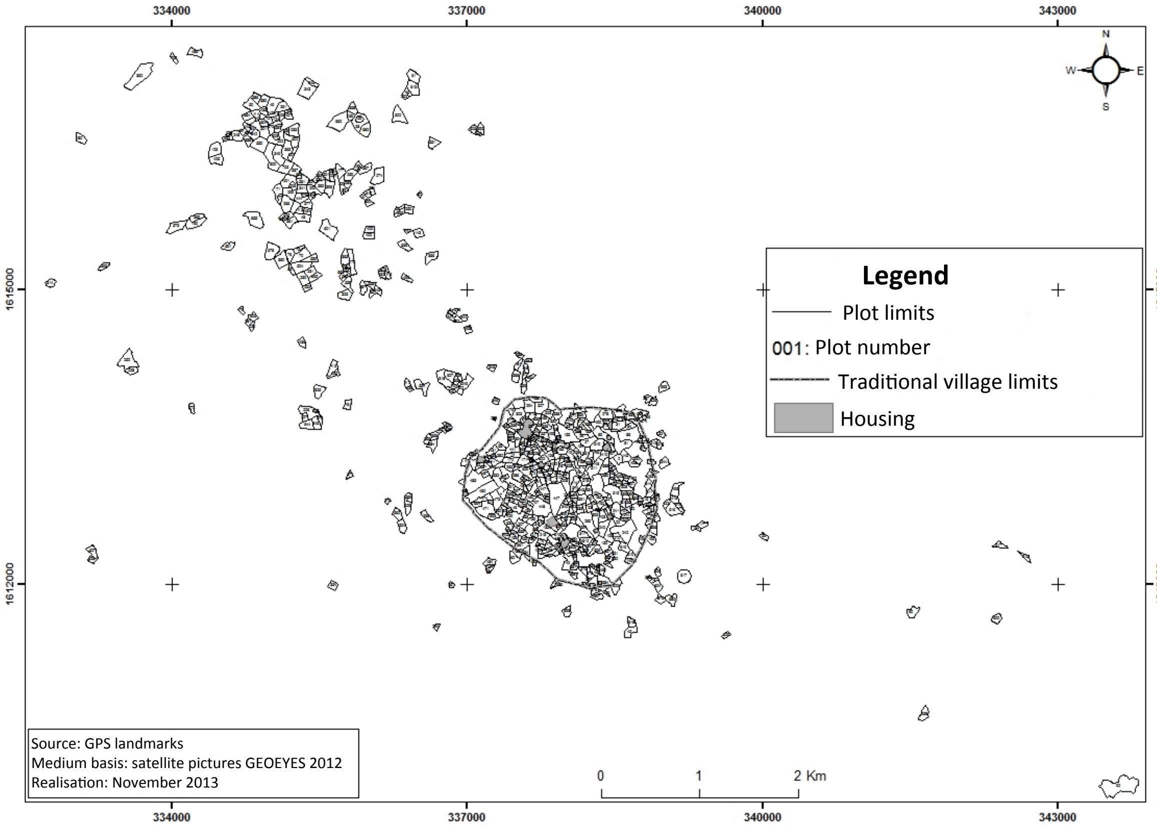
Month	Nitrogen content (kgN/kgDM)
January	0.0162
February	0.0141
March	0.0144
April	0.0156
May	0.0150
June	0.0162
July	0.0188
August	0.0191
September	0.0187
October	0.0182
November	0.0175
December	0.0153

Appendix 8 : Dry matter content kgDM/kgRM and nitrogen content kgN/kgDM for the different terroir components

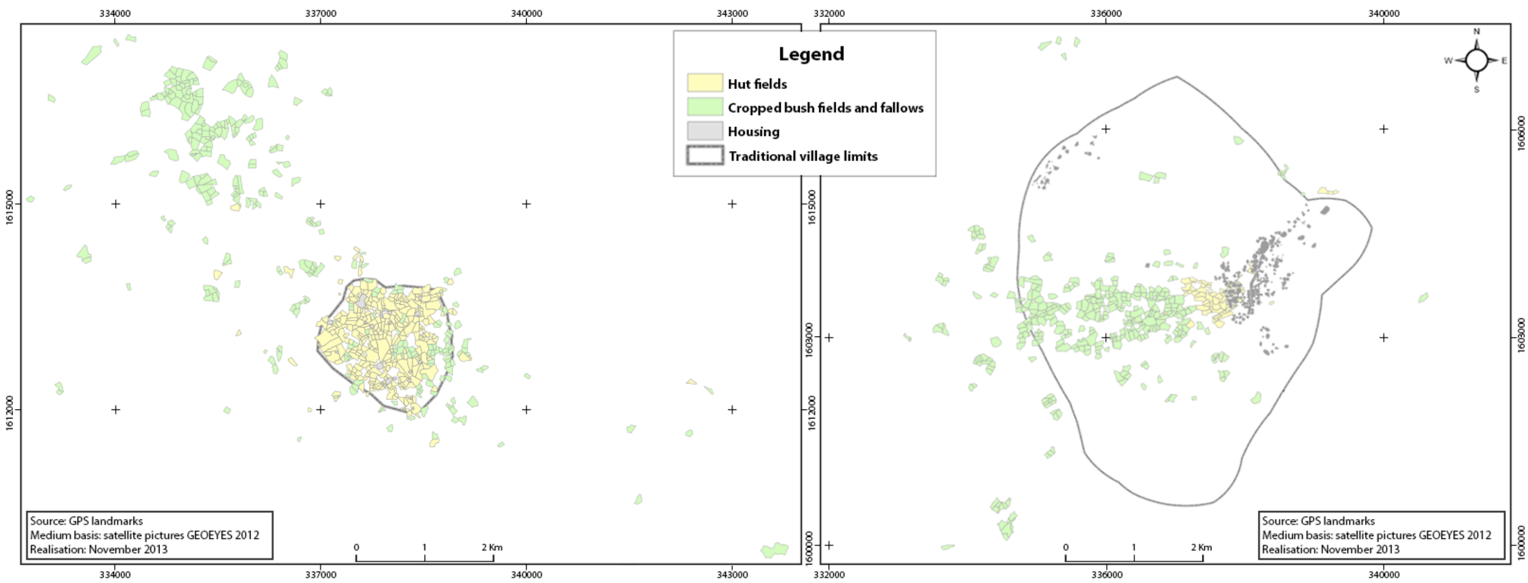
Flow nature	**Dry matter content (kgDM/kgRM)**	**Reference**	**Nitrogen content (kgN/kgDM)**	**Reference**
Corn grain	0.912	Le Thiec 1996	0.01664	Le Thiec 1996
Millet grain	0.925	Le Thiec 1996	0.01920	Le Thiec 1996
Sorghum grain	0.910	Le Thiec 1996	0.01728	Le Thiec 1996
Groundnut grain	0.860	Le Thiec 1996	0.06224	Le Thiec 1996
Watermelon grain	0.089	estimated	0.00096	estimated
Cowpea grain	0.892	Maliboungou et al. 1998	0.04466	Maliboungou et al. 1998
Bissap grain	1.000	USDA Nutrient Laboratory 2013	0.00100	USDA Nutrient Laboratory 2013
Groundnut hay	0.896	Le Thiec 1996	0.01700	Manlay 2001
Millet straw	0.881	Le Thiec 1996	0.00270	Manlay 2001
Sorghum straw	0.896	Le Thiec 1996	0.00544	Le Thiec 1996
Cowpea hay	0.902	Le Thiec 1996	0.02395	Le Thiec 1996
Watermelon stalk	0.089	estimated	0.00096	estimated
Corn stalk	0.895	Le Thiec 1996	0.00800	Manlay 2001
Corn cob	0.650	Alvarez et al. 2013	0.01210	Manlay 2001
Millet bale	0.989	Manlay 2001	0.01230	Manlay 2001
Sorghum bale	0.998	Manlay 2001	0.01600	Manlay 2001
Groundnut pod	0.865	Le Thiec 1996	0.02870	Manlay 2001
Watermelon	0.089	ANSES 2012	0.00096	ANSES 2012
Bissap flower	0.405	Courtial et al. 1998	0.02410	Courtial et al. 1998
Rice	0.870	Alvarez et al. 2013	0.01500	Alvarez et al. 2013
Meat	0.800	Huss 1999	0.25000	Huss 1999
Fish	0.265	Huss 1999	0.11169	Huss 1999
Compact manure	0.320	Alvarez et al. 2013	0.01600	Alvarez et al. 2013

Flow nature	Dry matter content (kgDM/kgRM)	Reference	Nitrogen content (kgN/kgDM)	Reference
Straw manure	0.450	Ganry and Badiane 1998	0.00500	Ganry and Badiane 1998
Sewage powder	0.450	Ganry and Badiane 1998	0.00440	Ganry and Badiane 1998
Animal feed residues	0.881	Le Thiec 1996	0.00270	Le Thiec 1996
Household wastes	0.500	Alvarez et al. 2013	0.00600	Alvarez et al. 2013
Wood	0.880	Louppe 2012	0.00300	Louppe 2012
Fresh herbs	0.311	Le Thiec 1996	0.02057	Le Thiec 1996
Acacia albida leaves	0.307	Wentling 1983	0.01552	Fall 1989
Dry herbs	0.343	Le Thiec 1996	0.00979	Le Thiec 1996
Fresh cowpea hay	0.203	Le Thiec 1996	0.02434	Le Thiec 1996
Baobab leaves	0.896	Abakar 2010	0.00900	Abakar 2010
Cotton grain	0.930	Le Thiec 1996	0.03072	Le Thiec 1996
Groundnut cake	0.860	Le Thiec 1996	0.08480	Le Thiec 1996
Rice bran	0.900	Le Thiec 1996	0.01795	Le Thiec 1996
Millet bran	0.910	Le Thiec 1996	0.02443	Le Thiec 1996
« Livestock feed»	0.210	Fall-Touré et al. 1997	0.02560	fieldwork observation
Acacia albida fruits	0.900	Fall-Touré et al. 1997	0.11220	Richard et al. 1990
Milk	-	-	0.005 (/kgMB)	Rufino et al. 2009
Urea	1	fieldwork observation	0.46	fieldwork observation
« Mil mineral fertilizer »	1	fieldwork observation	0.15	fieldwork observation
« Groundnut mineral fertilizer»	1	fieldwork observation	0.10	fieldwork observation
Urine	0.075	Audoin 1991	0.000675	Audoin 1991

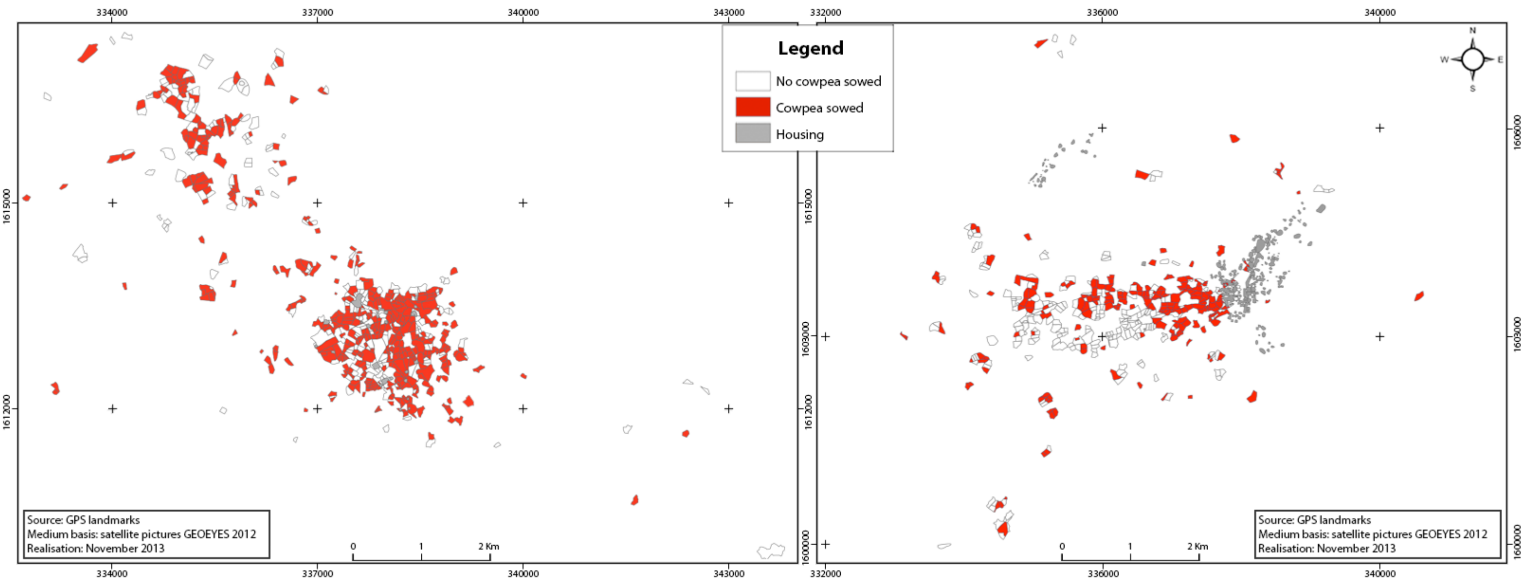
Appendix 9 : Plot distribution for Barry Sine, Source Ndiaye and Thiaw 2013



Appendix 10: Plot distribution according to the distance from the owner's housing for Barry Sine and Sassem in 2012, Source Ndiaye and Thiaw 2013



Appendix 11: Women land access according to plot benefiting from cowpea intercropping for Barry Sine and Sassem in 2012, Source Ndiaye and Thiaw 2013



Appendix 12 : Nitrogen balance group according to 2012's crop for Barry Sine and Sassem

Barry Sine :

Crop in 2012	Nitrogen balance estimated	Groups	
Corn	22.811	A	
Fallow	-14.625	B	
Pod	-23.439	B	
Groundnut	-28.108	B	
Bissap	-30.863	B	
Sorghum	-37.226	B	
Precocious cowpea	-97.296		C

Sassem

Crop in 2012	Nitrogen balance estimated	Groups			
Market gardening	49.032	A			
Pastureland + Paddocking area	13.944	A	B		
Fallow	2.626		B		
Pastureland	-3.281		B		
Pod	-5.894		B		
Sorghum	-9.819		B	C	
Matye+Sorghum	-10.028		B	C	D
Pod+*Matye*	-12.127		B	C	D
Matye	-12.695		B	C	D
Pod+ *Matye*+Sorghum	-13.071		B	C	D
Pod+Sorghum	-17.298			C	D
Groundnut	-20.507			C	D
Late cowpea	-28.073				D
Matye+Groundnu	-32.496				D

Appendix 13 : Crop nitrogen efficiency grouping in 2012 for Barry Sine and Sassem

Barry Sine

Crop in 2012	Average nitrogen efficiency in 2012 estimated	Groups		
Precocious cowpea	9.689	A		
Sorghum	2.523		B	
Bissap	0.638		B	C
Pod	0.159			C
Groundnut	-0.120			C
Fallow	-0.429			C
Corn	-0.888			C

Sassem

Crop in 2012	Average nitrogen efficiency in 2012 estimated	Groups		
Late cowpea	210.350	A		
Matye	177.194	A	B	
Sorghum	160.509	A	B	
Pod+*Matye*+ Sorghum	137.161	A	B	
Pod+*Matye*	119.225		B	
Pod+Sorghum	107.245		B	
Pod	93.452		B	
Pastureland	31.288			C
Matye+Sorghum	-3.155			C
Market gardening	-3.247			C
Pastureland+ Paddocking	-15.438			C
Groundnut	-15.647			C
Fallow	-20.897			C
Matye+Grountnut	-35.081			C