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Food security and better livelihoods
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Smallholder agricultural livelihood livelihood type-specific behaviour analyses for better targeting adoption of sustainable land management: A demonstrative case analysis in Pontieba, south-western Burkina Faso

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Abstract

The support to the transition of Agricultural Livelihood System in dryland areas poses the need of better sizing actual farming system structure and functioning. This study was conducted in the frame of a research on dry areas aiming proposing an agent-based model of smallholder Agricultural Livelihood Systems (ALS) in the village of Pontieba, Southern Burkina Faso. The study used a previously formulated ALS typology to analyse land-use decision making by each ALS type. Multi-nominal logistic (M-Logit) regressions and Bi-Logit were used to estimate the effects of wide ranges of land conditions, livelihood characteristics and access to rural credits on household's adoption of crop and nutrient adoption uses. The regressions used multi-dimensional nested household-plot data generated by combining household survey and GIS analysis. The results showed that the main significant drivers for both crop choice model and nutrient management adoption model were Household head age and his education, household size, Plot distance from household homestead, plot size, crop history on the plot and household enabling policies. Common and livelihood system type-specific drivers were identified. The study demonstrated the role of heterogeneity in farm behaviour. It provides with useful information for farming design studies, policy intervention, and moreover for agent-based modelling of smallholder Agricultural Livelihood Systems.

Keywords: Sustainable Agricultural livelihoods, decision making, semi-arid areas, integrated systems modelling, Burkina Faso

1. Introduction

Farming in general and the smallholder farming in Sub-Saharan Africa need more than ever to be redesigned. In effect many challenges arise given on one hand the context of continuous population growth and the resulting degradation of natural resources which form the basis of food and non-food agricultural production, and on the other hand the effects of climate change. These challenges are among others the need for sufficient and qualitative nutrition, profitable crop and livestock production, poverty alleviation, the preservation of production resources (land, forest and water) and adaptation to uncertainties.

The key concepts illustrating this need of change are the concepts of sustainability and of resilience (Darnhofer *et al.*, 2012; Tendall *et al.*, 2015). The sustainability can be seen as aiming at achieving present livelihood goals while preserving the capacity of still achieving them in the future (Maleksaeidi and Karami, 2013). Resilience seen as complementary to sustainability (Tendall *et al.*, 2015) defines the capacity over time to face disturbances in order to still fulfil the system functions.

The transformation of actual smallholder agricultural livelihood systems into sustainable agricultural livelihood systems requires the support of system research that can help better apprehending farm structure and functioning. This improvement in the understanding of the farming system is a pre-requisite to a successful and sustainable transition of agricultural livelihood systems. Indeed agricultural livelihood systems are characterised by their high heterogeneity in terms of structure (Le, 2005; Tittonell *et al.*, 2008; Thiombiano and Le, Submitted) and functioning (Thiombiano and Le, 2015b). This heterogeneity influences the farm behaviour in the adoption of proven technologies (Thiombiano and Le, 2015a) in terms of land-use decision making (Le, 2005).

The present study conducted in the village of Pontieba is situated in the frame of a research which global objective is to perform an agent-based modelling of agricultural livelihood system in the region. The main objective of this study is to conduct a behavioural analysis of the different Agricultural Livelihood Systems identified in the village of Pontieba by Thiombiano and Le (2015b). The specific objectives pursued by the study is (i) to determine factors influencing the land-use choices of the different agricultural livelihood systems and (ii) to identify the determinants of the main soil nutrient management practices in Pontieba by each agricultural livelihood system type.

2. Methods and materials

2.1. Study site

The present study was performed in the south-western Burkina Faso in the village of Pontieba located 11° 7' 0" North and 3° 7' 0" W. The village is situated in Ioba province close to Dano, the capital town of the province (see Fig.1). The south-western region belongs to the South-Sudanian climatic zone and is one the regions receiving more rains in Burkina Faso. However the rainfall is declining. From above 1,000 mm per year in the past, the region and the Ioba Province in specific has nowadays an average annual rainfall of 900-965 mm according to records from the provincial direction of the ministry of agriculture. The vegetation cover is savannah and is declining as well. The main soil type encountered in Ioba province and in the village of Pontieba is leached ferruginous tropical soils, hardened in some locations (Thiombiano, 2015). Subsistence agricultural activities are the main source of livelihood in the village. However, land pressure due to population growth (2.5%) (INSD, 2009), land degradation, and rainfall decrease and variability are increasing threat to population livelihood. Cereals and cotton are the main cultivated crops in the village.

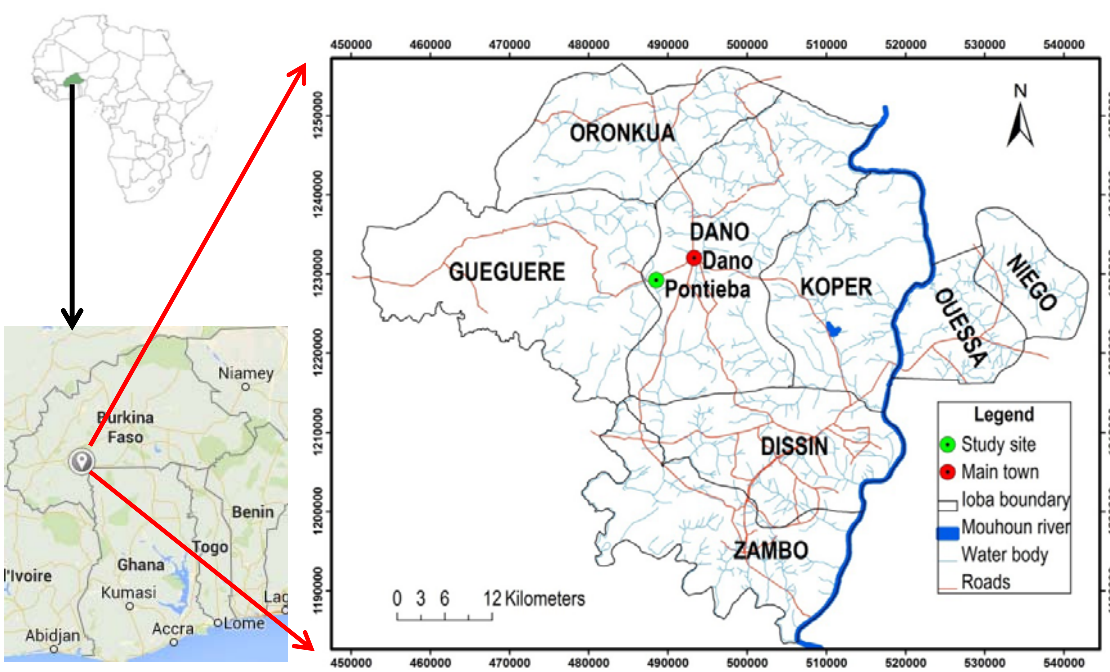

Fig. 1. Study site. Source: Thiombiano and Le (Submitted). Notes: Text labels with capital and normal characters are for communes and villages, respectively. Dano is the main town of Ioba province.

2.2. *Study design*

This study is part of a research aiming at regionally adapting the LUDAS model (Le, 2005) to West African farming systems by modelling smallholder agro-ecological livelihood systems in a drylands area of Burkina Faso. The first step of the research consisted in formulating an agro ecological livelihood system (ALS) typology in the research area, the village of Pontieba in Ioba province, South-western Burkina Faso (see Thiombiano and Le(2015b)). The identified typology will serve to define different human agent types in the modelling part. The present study, as illustrated in Fig.2, performs behavioral analyses of the different ALS in terms of crop choice and nutrient management practices adoptions.

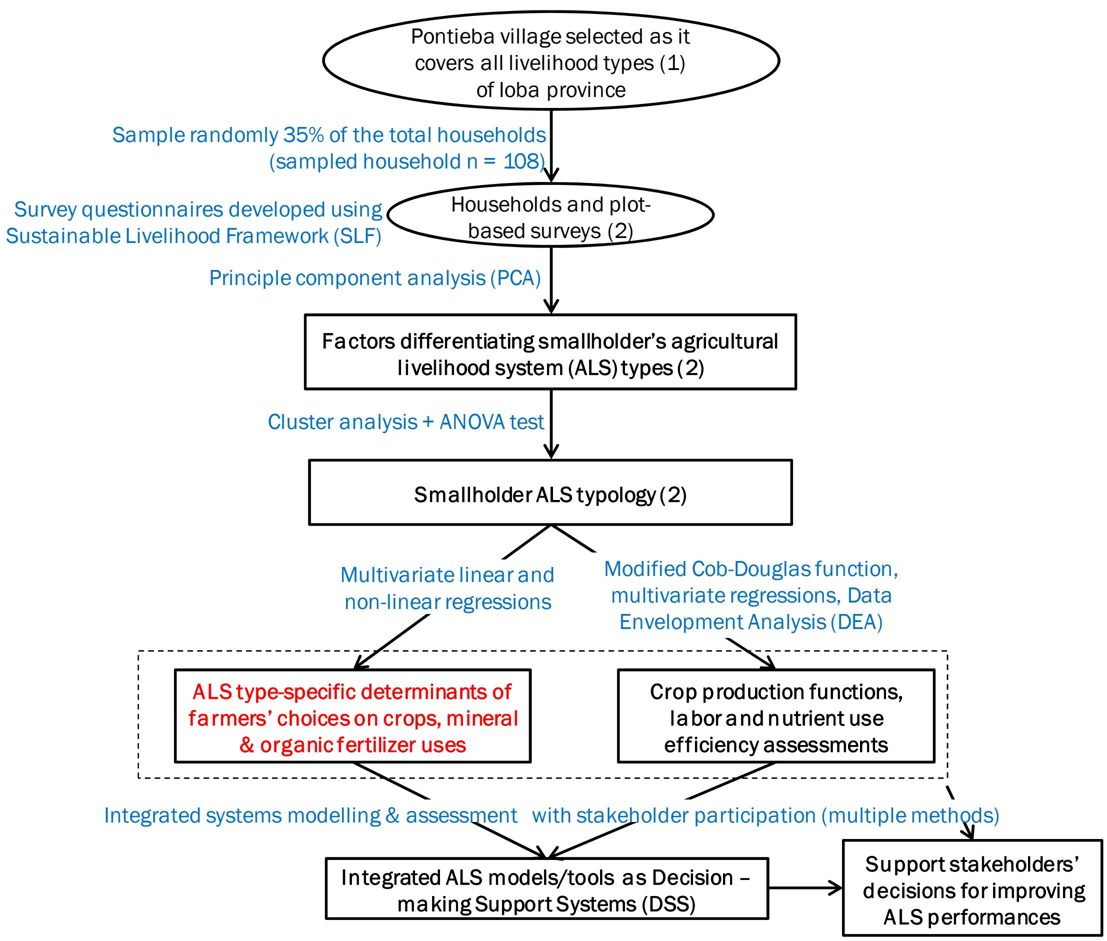

Fig.2. Corresponding step of the current study (box with red text) in the analytical flow towards integrated ALS models/tools as decision support systems (DSS) for improving ALS outcomes. Sources/references: This figure is adapted from Le (in prep.); (1) Thiombiano and Le (submitted), (2) Thiombinano and Le (2015b).

Dependent variables considered for behavioral analysis

The behavioral analyses comprised crop choice decision making and nutrient management practices adoptions. Smallholder farms usually grow different crops on their farm lands either in sole or in association. The main crops grown in Pontieba are cereals (Sorghum, maize, rice, millet), legumes (groundnuts, cowpea, soya), and cotton as non-food cash crop. Given the lack of permanent water body in the village, dry season irrigated crops are rarely practiced. Due to the fact that few plots with consistent crop association were encountered and also for the sake of avoiding complexity, only main primary crops were considered in this study. Based on the summary of the number of plots per crop type in the collected dataset (see supplementary material TableS1) we retained the following options for crop choice: Sorghum or millet, Groundnuts, Rice, Maize, and Cotton. The dependent variable Crop choice for a given plot (P_{CROP}) was then coded as: P_{CROP} = 1 if “Sorghum or millet”; =2 if Groundnuts; = 3 if Rice; = 4 if Maize; and = 5 if Cotton.

Regarding nutrient management, the main practices observed in Pontieba were the use of mineral nutrient, organic nutrient (compost and animal manure), and stone bunds which are soil erosion control technology. However, only few plots with stone bunds were observed and most of the time it was inconsistently implemented. Therefore, three dependent variables for nutrient management were formulated:

- P_{MIN}: Adoption of mineral nutrient use on the plot (=1 if yes, = 0 otherwise)
- P_{ORG}: Adoption of organic nutrient use on the plot (=1 if yes, = 0 otherwise)
- P_{MINORG}: Adoption of combined mineral-organic nutrient use on the plot (=1 if yes, = 0 otherwise)

Independent variables selected for behavioral analysis

The choice of the farmer to allocate crops to a given land patch (plot) and his adoption of nutrient management practices are influenced by socioeconomic and biophysical factors. Guided by the Sustainable Livelihood Framework (SLF) we selected candidate influencing factors of crop choice decision making and of nutrient management practices adoptions by farmers from literature and from common sense appreciation. We distinguished three main types of variables: (i) Household variables nested to (ii) plots variables and (ii) credit access enabling policy variable.

Household variables

Household variables describe household settings. The age of household head ($H_{HEADAGE}$) denotes his accumulated experience in terms of farming practice and may play a significant role in the farmer decision to grow a crop (Ayele *et al.*, 2015). The age may additionally indicate the farmer's behavior towards risk and uncertainties, older farmers being likely more risk averse than younger farmers. The age of household head is then expected to be an influencing factor of crop choice (Le and Feitosa, 2012) and of soil nutrient management practices adoption (Yilma and Berger, 2006; Ketema and Bauer, 2011; Thiombiano and Le, 2015a).

The number of years of classic education of the household head (H_{HEDUYR}). Crop choice by the farmer depends on his assessment of the socio-economic and biophysical context of the farm. This assessment is greatly influenced by his level of classic education which may improve the farmer's understanding of the farm environment and the resulting challenges. An educated farmer may then choose a more suitable crop given the perceived soil fertilizer condition, climatic risk or economic opportunities than a non-educated one. He may also better understand the need for sustainable management of soil fertility instead of short term profitable farming practices without preserving soil health. Le and Feitso (2012) and Ayele et al. (2015) showed that education was a significant influencing factor of crop choice in Vietnam and Ethiopia respectively. Freeman and Omiti (2003) and Thiombiano and Le (2015a) supported that education of the household head had an influence on the adoption of soil nutrient use by farmers. Therefore, the number of years of classic education of the household head is expected to influence crop choice and augment the chance of adoption of nutrient management practices by farmers of the study site.

The household size (H_{SIZE}) denotes the number of people depending on the farming activities for their livelihood. A large household may compel the farm to grow a particular type of crop to meet household food demand. For instance a large household may prior subsistence food crops compared to relatively small household which has less people to feed. Ayele et al. (2015) showed in Ethiopia that farms with large size tended to choose crops that allow them to fill food consumption gap. Besides, in order to increase food production, large farm may also be compelled to intensify food production by adopting soil nutrient use practices(Thiombiano, 2015). Therefore this variable is expected to positively affect the adoption of soil nutrient use.

Household's dependency ratio (H_{DEPEND}). This variable illustrates the number of inactive persons to take care of by active member of the farm. A high value of the variable is likely to drive the farmer to choose subsistence crop instead of a cash crop.

Number of workers of the farm (H_{LABOUR}). In general smallholder farms rely almost exclusively on family labor for farming activities. They generally have limited possibilities for hiring payed labour. So, a small number of workers may constraint the choice of growing labour intensive crops like cotton. Insufficient labour may also prevent the farmer from adopting nutrient use practices such as organic nutrient that are labour intensive for gathering nutrient resources and doing the composting. We then hypothesize that H_{LABOUR} will affect the choice of crops and increase the probability for a farm to adopt soil nutrient use.

Number of Tropical Livestock Units (H_{TLU}). Livestock considered as a form of savings in African smallholder farming systems (Zaibet *et al.*, 2010) is a source of cash income. It can be sold and the money used for purchasing mineral fertilizers that allow growing high nutrient demanding crops like maize or cotton. Besides, animal manure forms a valuable source of soil nutrient that can be used to complement the use of mineral nutrient which is often expensive for most smallholders. Also, livestock serves as draught for ploughing and for transportation in rural areas. It may favors the cropping of labor demanding crops or facilitate access to plots remoted from homestead comparatively to a situation of no access to animal drought. The livestock endowment is then expected to augment the chance of adoption of soil nutrient use as supported by Thiombiano and Le (2015a) and also influence the choice of crop allocation to a plot given its location and fertility conditions.

Annual gross income per capita ($H_{GROSSINCCP}$). Given the particular technical requirement of some crops (e.g. equipment, labour or soil nutrients) a low income farm may not be able to afford the production costs. For instance low labour farms may still grow labour intensive crops due to their financial endowment that allow hiring additional labour. Also, one the most important constraints of African smallholder farmers is power that limit adoption of sustainable practices like soil nutrients (Yilma and Berger, 2006; Amekawa, 2013). The variable $H_{GROSSINCCP}$ is expected to determine crop choice (Le, 2005) and to the adoption of soil nutrient use (Thiombiano and Le, 2015a).

Farm land holdings ($H_{HOLDINGS}$). The total farm land under cultivation in the farm is a driver of crop choice (Le, 2005). Subsistence based smallholder farms may prioritize food crops when they are land constrained. They may choose to grow marketable food crops or non-food cash crops only when the have enough land for subsistence food crops.

Plots variables

These variables illustrated the biophysical conditions which define the suitability of a plot to a particular crop. *Plot distance from homestead* (P_{DHOUSE}). One of the characteristics of smallholder farms is the spatial variability of soil fertility (Tittonell *et al.*, 2005b). Plots at homestead or close-by receive much more attention and are therefore more fertile than remote plots also called bush fields. The remoteness may prevent transportation of nutrient resources to plots. Because of this fertility gradient the distance of plot from household is expected to influence the choice of the crop grown on a plot (Le and Feitosa, 2012). Remote field will likely be allocated to less demanding crop in terms of fertility (i.e. sorghum and millet) while home field plots are likely to be allocated to crops like maize which is more demanding in terms of soil fertility.

The Plot size ($P_{PLOTSIZE}$) relates to the area available on the land patch for growing crops. When this area is large, the farmer will tend to grow crops requiring relative large land area or most important crops depending on the livelihood orientation: subsistence-based versus market-based agricultural livelihood. Large plot area also means more nutrients to be applied and then more expenses. We expect the size of the plot to influence crop choice as found by Ayele et al. (2015) in Ethiopia. Plot size is also expected to determine soil nutrient adoption (Yilma and Berger, 2006).

Type of crop grown on the plot ($P_{CROPTYPE}$). The type of crop grown on the plot is likely to determine the adoption of nutrient use. In effect, different crops types have not the same need in nutrient and are usually not given similar attention for fertilizer use. Legume crop contribute to enrich the soil through to the biological N fixation. These crops then reduce the nutrient mining effect (Enyong et al., 1999). Cereal crop like sorghum and millet are less demanding in nutrient compared to maize, rice or cotton. When the crop on the plot is cotton, maize or rice, the farmer has more chance to adopt nutrient use (Thiombiano, 2015).

Crop history of the plot ($P_{CROPHIST}$). As previously stated, different crops have different nutrient needs and play different role in terms of soil nutrient mining. This fact is used by farmers to determine crop rotation. Most of the time legume crops which are nitrogen fixing crops are used to restore soil fertility and a different crop is grown in the following year. Also, the rotation cotton-maize or cotton-sorghum is often used as rotation strategy by farmers to benefit from the residual fertilizer effect from the previous year. Therefore the crop history, crop grown in the previous year, is expected to determine the type current crop choice.

Plot's upslope contributing area ($P_{UPSLOPE}$) is the area contributing to water collection on the plot. It contributes to increase the wetness of the plot and therefore is expected to influence crop choice on the plot.

Plot's wetness index ($P_{WETNESS}$). This variable is an estimation of moisture level on the plot. The highest the wetness index the highest the moisture level of the plot. In most dryland areas the availability of water in soils during growing season is a major constraint affecting crop survival and productivity. Farmers usually allocate moisture demanding crops like rice and maize to land patches for which the perceived moisture potential is high while lands with perceived low moisture potential are allocated to drought resistant crops like sorghum and millet. The wetness index calculated from terrain analysis is expected to positively influence the allocation of plots with high wetness index value to water demanding cereal like rice and maize.

Plot's slope length factor (P_{LS}) indicates the erosion risk. Unless consistent erosion control measure are taken, the slope length factor will tend to reduce the chance of allocating nutrient and moisture demanding crops like maize and rice. Farmers may favor more drought resistant crop like sorghum on plot with high LS value.

Household access to enabling policy

Plot's owner access to credit (P_{CREDIT}): The access to a credit system allows the farmer to lessen the effect of low income. This improves the chance for the farmer to adopt soil nutrient use. Crop-targeted credit system may compel the farmer to choose this particular crop because of the opportunity he has to access soil nutrient.

Table 1: Description of hypothesized explanatory variables for crop choice and nutrient management (NM) practices adoption modeling

Variable	Definition	Considered (x) in		Data source
		Crop choice analysis	*NM adoption analysis*	
Dependent variables				
P_{CROP}	Crop choices (=1 if sorghum or millet, =2 if groundnuts, =3 if rice, =4 if maize and =5 if cotton)	x		On-farm interview
P_{MIN}	Adoption of mineral fertilizer use on the plot (= 1 if yes, = 0 if no)		x	On-farm interview
P_{ORG}	Adoption of organic fertilizer use on the plot (=1 if yes, = 0 if no)		x	On-farm interview
P_{MINORG}	Adoption of combined mineral-organic fertilizer use on the plot (=1 if yes, =0 if no)		x	On-farm interview
Household characteristics				
$H^{HEADAGE}$	Age of household head (year-old)	x	x	On-farm interview
H_{HEDUYR}	Number of school years the household head passed	x	x	On-farm interview
H_{SIZE}	Number of farm members	x	x	On-farm interview
H_{LABOR}	Number of workers	x	x	On-farm interview
H_{DEPEND}	Dependency ratio (= no. of dependents / no. of workers)	x	x	On-farm interview
H_{TLUCP}	Number of Tropical Livestock Units (TLU) of the household	x	x	On-farm interview
$H_{GROSSINCCP}$	Household annual gross income per capita (F CFA/person)	x	x	On-farm interview
$H_{HOLDINGS}$	Total holding land possessed by the farm (ha)	x	x	GPS and GIS-based measure
P_{DHOUSE}	Distance from plot to homestead (m)	x	x	GIS recordings
$P_{PLOTSIZE}$	Plot size (ha)	x	x	GPS measurement
$P_{CROPTYPE}$	Type of current crop grown on the plot (= 1 if fertilizer-demanded crops (maize, rice or cotton); =0 if other crops)		x	On-farm interview
$P_{CROPHIST}$	Type of previous crops grown on the plot (= 1 if the previous crops are fertilizer-demanded ones (maize,	x		On-farm interview

	rice or cotton); =0 if other crops)			
$P_{UPSLOPE}$	The upslope contributing area (m^2) at the plot location, indicating sedimentation accumulation potential	x	x	Terrain analysis from DEM
$P_{WETNESS}$	Topographical wetness index (= *ln* ($P_{UPSLOPE}$/surface slope)), indicating potential water saturation	x	x	Terrain analysis from DEM
PLS	The slope length (LS) factor at the plot location, indicating soil erosion potential.	x	x	Terrain analysis from DEM
<u>Household access to enabling policy</u>				
P_{CREDIT}	Plot's owner access to credit (= 0 if no, =1 if yes)	x	x	On-farm interview

2.5. Inferential statistical methods

Logistic regressions are models allowing identifying determinants of a given choice by agents. The aim of this study is to model smallholder decision making on crop choice and nutrient management practices at plot level. On a given plot farmer may grow more than one crop in association, but with a dominant/primary crop. We focused on primary crops on each plot. We considered in that case that the choice by the farmer to grow a particular crop does not depend on another crop being chosen. The famer makes independent choice among many possibilities. For modelling multiple choices multinomial logistic regressions are used. For the nutrient management practices, the farmer has the possibility of using more than one practice at a time on a plot. And the choice of using one practice may depend on the use of another practice. This prevent from using multinomial logistic regression models for nutrient management. We therefore used binary logistic (Bi-Logit) regression which model the probability for a practice to be used.

A multinomial logistic regression (M-Logit) is a general model of utility maximization (Le, 2005). This model expresses the probability (P_i) for an agent to choose the i^{th} crop in the function of the form:

$$P_i = \frac{\exp(V_i)}{\sum_j \exp(V_j)} \qquad (1)$$

V_i, the deterministic term of the utility function can be written in a form of a linear function as follow:

$$V_i = \beta_{i1} X_{i1} + \beta_{i2} X_{i2} + \ldots + \beta_{ik} X_{ik} + \beta_{i0} = \sum_k \beta_{ik} X_{ik} + \beta_{i0} \quad (2)$$

Equations 1 and 2 allow to finally expressing the M-logit model as follow:

$$P_i = \frac{\exp(\sum_k \beta_{ik} X_{ik} + \beta_{i0})}{\sum_k \exp(\sum_k \beta_{ik} X_{ik} + \beta_{i0})} \quad (3)$$

where β_{ik} are the model parameters estimated by the maximum likelihood method.

The dependent variable Y expressing the adoption of nutrient management practice has two issues: =1 if adoption takes place and 0 if not. The Bi-Logit model expressing the probability of adoption occurrence can be written as:

$$P(Y = 1) = \frac{\exp(\sum \beta_i X_i + \beta_0)}{1 + \exp(\sum \beta_i X_i + \beta_0)} \quad (4)$$

where β_i are the model's parameters estimated by the maximum likelihood method.

For estimating the paramerters β_{ik} and β_i of the MNL models (crop choice) and of the Bi-Logit model (nutrient adoption) we used explanatory variables summarized in Table 1. To estimate the parameters of an M-logit model for land use choices in Pontieba we used a plot-based dataset of household-farms and the software SPSS 20.

2.2. *Data source* and main farm types in Pontieba

Data source

The data used in this study was taken from Thiombiano and Le (2015b). They conducted surveys in year 2014 in the village of Pontieba. Using the Sustainable Livelihood framework (SLF) they collected a multidimensional dataset from 108 households-farms selected randomly. The semi structured questionnaire used covered the five dimension of the sustainable livelihood framework (Human, Physical, natural, financial and social capital). The human capital dimension covered farm-household demography and labour, education and training received by household-farm members. The Physical capital dimension comprised inventory of household and farm tools, and household access to road. For the natural capital dimension, the questionnaire collected land holdings of the farm-households. The financial capital dimension comprised farm cash income (annual livestock and crops sells, and off-farm income), received remittances, crop productions, and farm livestock inventory. The fifth dimension, social capital, was captured through household-farms membership to farmers association and groups. The dataset set also comprises geographical data from Geographical Positioning System (GPS) records, as well as Land use and Digital Elevation Model (DEM) data. The agricultural livelihood typology used in this study was formulated by Thiombiano and Le (2015b) for Pontieba.

Main agricultural livelihood types in Pontieba

Three main livelihood types were identified in the village of Pontieba by Thiombiano and Le (2015b) based on asset endowment and livelihood orientation.

Livelihood type I: Poor, landless and subsistence-based farms

This livelihood type is characterized by lowest asset endowment in terms of land, transport, labour and annual revenue. The land holding per farm member is less than 0.5 ha (0.47 ha per person). The annual gross income is 46,152 FCFA per person. This income lies below the national poverty line estimated to be 108,454 FCAF (USD 219.36/person/year). The production system is subsistence-based with sorghum, millet and maize being the main produced cereals. A low share of lands (10.74%) is allocated to cotton which is the main cash crop in the village.

Livelihood type II: Medium-income, high-dependency, cotton-and livestock-turned

Farms of the livelihood type II can be distinguished from farms of other livelihood types by their high dependency ratio (0.37) and their medium annual income estimated to be 101,295 FCFA/person (USD 204.88/person/year). This revenue is slightly below the poverty line in Burkina Faso, estimated to be USD 219.36/person/year. The livelihood is market-turned as 20% of the cultivated land is allocated to cotton cropping. The number of Tropical Livestock Unit (TLU) per capita was 0.23.

Livelihood type III: Better-off, land-and labour-rich, cotton-and livestock-turned

The agricultural livelihood type III is the best endowed and wealthiest farm type in Pontieba. It had the highest labour endowment (7 workers), the highest land holdings (4.25 ha) and the highest number of transportation (4). The livestock endowment was 0.35 TLU per person. The livelihood type III is market- turned: farms allocate around 23% of cultivated land to cotton, the main cash crop in the region. The agricultural livelihood type III was the only one farm type with annual income above the poverty line in Burkina Faso. This annual income was 144,428 FCFA/person (USD 292.12/person).

3. Results

3.1. Evaluation of models performance

To avoid multicollinearity (i.e. auto-correlations among explanatory variables at a degree violating the assumption of their independency in the statistical model), we used Variance Inflation Factor (VIF) and contingency coefficient to check the existence of multi-collinearity. There is risk of multi-collinearity when VIF is greater than 5 and contingency factor is less than 0.2 (DeFries *et al.*, 2010). The Chi-square test was used to evaluate models' overall performance of logistic regressions. The models' goodness-of-fit was evaluated using area under the Receiver Operating Characteristic (ROC) curve (Hosmer and Lemeshow, 2000). For values of area under ROC of 0.60-0.70, the model's performance is appreciated to be poor. For values of area under ROC between 0.70 and 0.80, the performance of the model is considered to be acceptable. It will be good if the area under ROC is between 0.8 and 0.90. When values are between 0.90 and 1, the performance of the model is excellent.

Crop choice model as well as nutrient adoption model was first estimated for the whole population without distinguishing separate agro ecological livelihood systems composing the whole population. Afterward, the models were estimated for each agro ecological livelihood systems.

3.1.1. Fitness and accuracy assessment of crop choice model

The chi-square test showed that the M-Logit model was highly significant ($p<0.01$) in explaining crop choice by farmers in whole population. The value of the Nagelkerke's pseudo-R^2 was 0.73, meaning that 73% of the variation of crop choice probability is explained by the selected independent variables. The values of the area under ROC (AU ROC) curve showed good accuracy for predicting the probability of "sorghum or millet" and "cotton" crops choice (AU ROC = 0.85 and 0.75, respectively). The prediction accuracy was very good for groundnuts (AU ROC=0.90), rice (AU ROC=0.95) and maize (AU ROC=0.91).

The chi-square test indicated that the M-Logit models for "Poor, landless and subsistence-based" agricultural livelihood system (ALS 1), "Medium-income, high-dependency, cotton and livestock-turned" agricultural livelihood system (ALS 2), and "Better-off, land-and labour-rich, cotton and livestock-turned" agricultural livelihood system (ALS 3) were all highly significant ($p<0.01$) in explaining crop choice by farmers.

The value of the Nagelkerke's pseudo-R^2 was found to be 0.85 for the M-Logit model for crop choice by farms of ALS 1 (Table 3), 0.79 for the M-Logit model for ALS 2 (Table 4), and 0.77 for the M-Logit model for ALS 3 (Table 5). These values indicate that 85%, 79% and 77% of the total variation of crop choice probability was explained by the set of independent variables included in the M-Logit model for ALS 1 (Table 3), ALS 2 (Table 4) and ALS 3 (Table 5), respectively. As for the accuracy performance of the models, M-Logit model for ALS 1 showed excellent performance for predicting the probability of "sorghum or millet" crops (AU ROC=0.92), groundnuts crops (AU ROC=0.93), rice crop (AU ROC=0.97) and maize (AU ROC=0.95). The accuracy performance for predicting the probability of cotton crop was good (AU ROC = 0.82) (Table 3). The M-Logit model for ALS 2 had excellent accuracy performance for predicting the probability of "sorghum or millet" crops choice (AU ROC=0.89), groundnuts crops choice (AU ROC=0.91), rice crop choice (AU ROC=0.96) and maize crop choice (AU ROC=0.89). The accuracy performance for predicting the probability of cotton crop choice was good (AU ROC = 0.82) (Table 4). Regarding ALS 3, the accuracy performance was good for predicting the probability of "sorghum or millet" crops choice (AU ROC=0.81), excellent for groundnuts crop choice (AU ROC=0.90), Rice crop choice (AU ROC=0.95) and maize crop choice (AU ROC=0.90). It was good for cotton crop choice (AU ROC=0.84) (Table 5).

3.1.2. Fitness and accuracy assessment of nutrient management practices adoption model

The estimation results indicated that the Bi-Logit model was highly significant in explaining the adoption of nutrient by farmers. In effect, the likelihood ratio test was highly significant ($p<0.01$) for whole population and for separate ALS types (Tables 6-8). The values of Nagelkerke pseudo-r^2 indicated that the model explained 48%, 63%, 62% and 56% of the total variation of the probability of mineral fertilizer adoption by farmers in whole population, ALS1, ALS2 and ALS3, respectively (Table 6). Additionally, the area under ROC (AU ROC) curve showed that the prediction accuracy of mineral fertilizer adoption probability was good for whole population (AU ROC=0.86), and excellent for ALS 1 (AU ROC = 0.93), ALS 2 (AU ROC = 0.91) and ALS 3 (AU ROC = 0.90). The model explained 32% (pseudo-r^2 = 0.32), 36% (pseudo-r^2 = 0.36), 50% (pseudo-r^2 = 0.50) and 62% (pseudo-r^2 = 0.62) of the total variation of organic nutrient adoption probability for whole population, ALS 1, ALS 2 and ALS 3, respectively (Table 7). The model accuracy performance for predicting the adoption of organic nutrient was good for whole population and for ALS 1 (AU ROC = 0.84 for both), excellent for ALS 2 (AU ROC =0.91) and for ALS 3 (AU ROC = 0.89). As for the adoption of combined mineral-organic fertilizer, the Nagelkerke pseudo-r^2 was evaluated to be 0.32 for whole population and 0.56 for ALS 1, 0.47 for ALS2 and 0.59 for ALS 3 (Table 8). This shows that the model explained 32% (for whole population), 56% (for ALS 1), 47% (for ALS2) and 59% (for ALS 3) of the total variation of combined mineral-organic nutrient adoption probability. The prediction accuracy (Table 8) was good for whole population (AU ROC = 0.86), and excellent for ALS 1 (AU ROC=0.96), ALS 2 (AU ROC=0.93) and ALS 3 (AU ROC=0.96).

The explanatory variables of the MLR and Bi-Logit models that were found significant varied across ALS types and did not have the same affecting direction and amplitude. We distinguished two types of drivers:

i. Common drivers that were found significant for whole population and individual ALS farm types. A common factor may not have same direction across different ALS farm types. Also a common affecting factor may be an aggregated effect of all farm types and be significant only for whole population while significant for none of the ALS farm types considered separately.
ii. Livelihood type-specific driver affects particular ALS farm types and may not appear as affecting factor for whole population.

3.2. Common drivers

3.2.1 Common drivers of crop choice by smallholder farms

Common drivers of groundnuts crop choice

The common variable Household size (H_{SIZE}) was the only common driversthat positively influenced the choice of groundnuts (Table 2). The variables Household labour (H_{LABOUR}), Dependency ratio (H_{DEPEND}), Plot distance from homestead (P_{DHOUSE}), Plot size (P_{AREA}) were all common driversthat reduced the chance for farmer to choose groundnuts crop compared to “sorghum or millet” crops. This indicates that in general farmers allocated labour and large plots to subsistence crops (sorghum and millet). All these common affecting factors, apart from P_{AREA}, were observed for whole population (Table 2) and were not significant for individual ALS farm types (Tables 3-5).

Table 2. MNL estimation of crop choice by whole population (n = 465 plots), using "sorghum or millet" crop as a base case

Variable	Coefficient (Standard error)			
	Groundnuts	Rice	Maize	Cotton
Constant	1.16 (1.35)	-3.43 (1.82)	0.71 (1.26)	-0.41 (1.09)
Household variables				
Age of household head ($H_{HEADAGE}$)	-0.02 (0.01)	0.02 (0.02)	-3.15E-03 (0.01)	-0.02* (0.01)
Household head education years (H_{HEDUYR})	0.07 (0.09)	0.17* (0.09)	0.11 (0.08)	-0.05 (0.07)
Household size (H_{SIZE})	1.10* (0.56)	0.33 (0.55)	0.37 (0.40)	-0.23 (0.36)
Household labour (H_{LABOUR})	-1.08* (0.65)	-0.32 (0.63)	-0.45 (0.46)	0.42 (0.41)
Dependency ratio (H_{DEPEND})	-6.64** (2.86)	-1.97 (2.51)	-1.34 (1.85)	1.73 (1.71)
Tropical Livestock Unit per person (H_{TLUCP})	0.72* (1.02)	1.58 (1.28)	0.76 (0.89)	0.33 (0.73)
Annual gross income per person ($H_{GROSSINCCP}$)	-2.82E-06 (4.32E-06)	-1.12E-05* (5.87E-06)	-8.36E-06** (4.22E-06)	2.89E-06 (3.81E-06)
Total farm land holdings ($H_{HOLDINGS}$)	0.10 (0.10)	0.17 (0.12)	0.09 (0.09)	-0.09 (0.09)
Plot variables				
Plot distance from homestead (P_{DHOUSE})	-4.18E-04* (2.32E-04)	-5.09E-05 (3.08E-04)	-1.63E-03*** (3.07E-04)	-4.23E-04** (1.83E-04)
Plot size (P_{AREA})	-3.10*** (0.62)	-11.50*** (1.90)	-3.24*** (0.68)	-0.37 (0.34)
Previous crop on the plot ($P_{CROPHIST}$)	-2.35*** (0.67)	4.15*** (0.84)	3.25*** (0.47)	0.27 (0.34)
Plot upslope ($P_{UPSLOPE}$)	-1.91E-06 (1.54E-06)	4.36E-07 (4.03E-07)	3.37E-07 (4.30E-07)	5.96E-07 (3.84E-07)
Plot wetness index ($P_{WETNESS}$)	0.10 (0.07)	0.18** (0.07)	0.01 (0.05)	-0.04 (0.05)
Slope length of the plot (P_{LS})	0.02 (0.14)	-0.15 (0.16)	-0.26* (0.14)	-0.17 (0.11)
Household access to enabling policy				
Access to credit (H_{CREDIT})	0.31 (0.40)	0.52 (0.50)	0.84** (0.38)	1.12*** (0.32)
Fitness and accuracy assessment of the model				
Likelihood ratio test	Chi-square = 547.45;	df=60;	p=0.000	
Pseudo r^2	=0.69 (Cox ad Snell); =0.73 (Nagelkerke); =0.39 (McFadden)			
Area under ROC Curve	=0.85 (Sorghum or millet); =0.90 (Groundnuts); =0.95 (Rice); =0.91 (Maize); =0.75 (Cotton)			

Note: Signs ***, **, and * indicate statistical significance at the 99% (P<0.01), 95% (P<0.05), and 90% levels (P<0.1), respectively.

Table 3. MNL estimation of crop choice by "Poor, landless and subsistence-based" " agro ecological livelihood system farm type (n = 151 plots), using "sorghum or millet" crop as a base case

Variable	Coefficient (Standard error)			
	Groundnuts	Rice	Maize	Cotton
Constant	0.51 (3.44)	-23.98 (5.65)	-0.65 (3.33)	3.26 (3.11)
Household variables				
Age of household head ($H_{HEADAGE}$)	-0.02 (0.04)	0.14** (0.07)	0.04 (0.04)	-0.08* (0.04)
Household head education years (H_{HEDUYR})	0.96** (0.44)	0.51 (0.37)	0.40 (0.31)	-0.32 (0.39)
Household size (H_{SIZE})	3.31 (2.03)	-3.46 (2.19)	-1.59 (1.33)	-1.29 (1.13)
Household labour (H_{LABOUR})	-3.22 (2.18)	3.53 (2.46)	1.32 (1.45)	1.38 (1.17)
Dependency ratio (H_{DEPEND})	-20.53 (12.58)	13.37 (13.74)	5.75 (7.27)	3.95 (4.59)
Tropical Livestock Unit per person (H_{TLUCP})	18.17** (7.59)	-3.32 (12.35)	-4.81 (5.72)	-4.98 (8.33)
Annual gross income per person ($H_{GROSSINCCP}$)	-7.26E-06 (2.15E-05)	-6.38E-05 (6.05E-05)	-1.90E-05 (1.88E-05)	-1.34E-05 (1.87E-05)
Total farm land holdings ($H_{HOLDINGS}$)	-0.05 (0.23)	0.03 (0.39)	0.11 (0.28)	-0.11 (0.27)
Plot variables				
Plot distance from homestead (P_{DHOUSE})	-5.96E-04 (6.78E-04)	8.61E-04 (1.23E-03)	-2.07E-03** (8.34E-04)	-1.86E-04 (4.24E-04)
Plot size (P_{AREA})	-7.14*** (2.41)	-13.01*** (4.07)	-3.67** (1.64)	0.20 (0.84)
Previous crop on the plot ($P_{CROPHIST}$)	-25.79 (4332.22)	23.36 (0.00)	6.26*** (1.75)	-0.55 (0.79)
Plot upslope ($P_{UPSLOPE}$)	-9.15E-06 (1.56E-05)	3.79E-06 (2.95E-06)	3.25E-06 (2.90E-06)	-1.24E-06 (4.86E-06)
Plot wetness index ($P_{WETNESS}$)	0.15 (0.19)	0.09 (0.17)	4.90E-03 (0.13)	0.07 (0.12)
Slope length of the plot (P_{LS})	0.37 (0.37)	-0.30 (0.36)	-0.60** (0.27)	-4.38E-03 (0.21)
Household access to enabling policy				
Access to credit (H_{CREDIT})	2.72** (1.38)	-1.62 (1.70)	-0.74 (1.04)	0.11 (0.84)
Fitness and accuracy assessment of the model				
Likelihood ratio test	Chi-square = 248.58;	df=60;	p=0.000	
Pseudo r^2	=0.81 (Cox ad Snell);	=0.85 (Nagelkerke);	=0.57 (McFadden)	
Area under ROC Curve	=0.92 (Sorghum or millet); =0.95 (Maize);	=0.93 (Groundnuts); =0.82 (Cotton)	=0.97 (Rice);	

Note: Signs ***, **, and * indicate statistical significance at the 99%, 95%, and 90% levels, respectively.

Common drivers of rice crop choice

Household head education years (H_{HEDUYR}) and Plot wetness index ($P_{WETNESS}$) were the common driversthat positively influenced the probability of rice crop choice compared to "sorghum or millet" crops (Table 2). Farms were likely to choose growing rice crop instead of "sorghum or millet" when the head is more educated and the plot wetter. The common driversthat reduced the chance of choosing rice crop were Annual gross income per person ($H_{GROSSINCCP}$), and Plot size (P_{AREA}) (Table 2). Indeed given that rice cropping is labour and nutrient intensive farmers usually cultivate plots of small size. Also due to the availability of wetlands in the village, only limited developed lands for rice cropping are available. Plot allocated by farmer is small because of the high demand. P_{AREA} is significant for all ALS types.

Common drivers of maize crop choice

Only Previous crop on the plot ($P_{CROPHIST}$) augmented the probability for farmers to choose maize crop (Table 2). For nutrient intensive previous crops the farmer is likely to grow maize to benefit from residual fertility. This practice may have more chance to occur when organic nutrient was applied or if previous crop was cotton. The others common affecting factors, Annual gross income per person ($H_{GROSSINCCP}$), Plot distance from homestead (P_{DHOUSE}), Plot size (P_{AREA}) and Slope length of the plot (P_{LS}) reduced the chance maize crop choice (Table 2). This is understandable since sorghum is the main multiple purpose cereal in the region. It is used for meals and for preparing local drink contrary to maize. The issue of nutrient transportation to distant plot and fertility gradient (Tittonell *et al.*, 2005), maize crop may not be allocated to remote plots. P_{LS} reflects the erosion risk on the plot and may also indicate less wetness potential requiring the farmer to grow more drought resistant and less nutrient demanding crop like sorghum or millet.

Common drivers of cotton crop choice

No common drivers were found for cotton crop choice. The underlying drivers of cotton crop choice were strongly influenced by agro ecological livelihood system types.

Table 4. MNL estimation of crop choices by "Medium-income, high-dependency, cotton and livestock-turned" agro ecological livelihood system farm type (n = 183 plots), using "sorghum or millet" crop as a base case

Variable	Coefficient (Standard error)			
	Groundnuts	Rice	Maize	Cotton
Constant	1.25 (3.54)	6.61 (5.07)	3.26 (3.50)	-6.17 (3.39)
Household variables				
Age of household head ($H_{HEADAGE}$)	-0.05* (0.03)	0.02 (0.03)	-9.86E-04 (0.02)	-2.38E-03 (0.02)
Household head education years (H_{HEDUYR})	0.22 (0.14)	0.14 (0.16)	0.13 (0.13)	0.06 (0.12)
Household size (H_{SIZE})	1.15 (1.00)	1.30 (1.04)	0.20 (0.68)	-0.94 (0.65)
Household labour (H_{LABOUR})	-0.75 (1.24)	-1.74 (1.36)	-0.21 (0.89)	1.85** (0.86)
Dependency ratio (H_{DEPEND})	-6.02 (5.21)	-7.65 (4.77)	-0.47 (3.16)	6.51** (3.13)
Tropical Livestock Unit per person (H_{TLUCP})	-0.60 (1.94v	1.66 (2.14)	1.54 (1.40)	2.28* (1.33)
Annual gross income per person ($H_{GROSSINCCP}$)	4.77E-06 (1.08E-05)	-1.16E-05 (1.64E-05)	-1.08E-05 (1.05E-05)	1.01E-05 (1.18E-05)
Total farm land holdings ($H_{HOLDINGS}$)	-0.07 (0.18)	0.04 (0.23)	0.04 (0.15)	-0.18 (0.15)
Plot variables				
Plot distance from homestead (P_{DHOUSE})	-4.60E-04 (3.92E-04)	1.67E-04 (5.53E-04)	-1.77E-03*** (4.99E-04)	-7.09E-04** (3.07E-04)
Plot size (P_{AREA})	-4.94*** (1.44)	-16.51*** (4.67)	-3.42*** (1.18)	0.56 (0.81)
Previous crop on the plot ($P_{CROPHIST}$)	-2.77** (1.08)	2.57** (1.19)	2.73*** (0.74)	0.90 (0.62)
Plot upslope ($P_{UPSLOPE}$)	1.75E-05 (1.47E-05)	2.43E-05 (1.50E-05)	2.37E-05 (1.50E-05)	2.37E-05 (1.49E-05)
Plot wetness index ($P_{WETNESS}$)	0.11 (0.15)	-0.13 (0.16)	-0.19 (0.12)	-0.20 (0.12)
Slope length of the plot (P_{LS})	-0.27 (0.30)	-1.17** (0.46)	-0.79** (0.31)	-0.70** (0.30)
Household access to enabling policy				
Access to credit (H_{CREDIT})	-0.25 (0.85)	-0.73 (1.00)	0.61 (0.70)	2.25*** (0.76)
Fitness and accuracy assessment of the model				
Likelihood ratio test	Chi-square = 255.69;	df=60;	p=0.000	
Pseudo r^2	=0.75 (Cox ad Snell); =0.79 (Nagelkerke); =0.45 (McFadden)			
Area under ROC Curve	=0.89 (Sorghum or millet); =0.91 (Groundnuts); =0.96 (Rice); =0.89 (Maize); =0.85 (Cotton)			

Note: Signs ***, **, and * indicate statistical significance at the 99%, 95%, and 90% levels, respectively.

Table 5. MNL estimation of crop choices by "Better-off, land-and labour-rich, cotton and livestock-turned" agro ecological livelihood system farm type (n = 131 plots), using "sorghum or millet" crop as a base case

Variable	Coefficient (Standard error)			
	Groundnuts	Rice	Maize	Cotton
Constant	11.24 (11.98)	-9.71 (11.13)	3.77 (10.22)	5.58 (6.10)
Household variables				
Age of household head ($H_{HEADAGE}$)	-0.04 (0.04)	0.04 (0.05)	4.80E-04 (0.03)	-0.04 (0.02)
Household head education years (H_{HEDUYR})	-0.85 (0.63)	0.56 (0.45)	0.52 (0.41)	-0.32* (0.19)
Household size (H_{SIZE})	-2.34 (3.31)	0.74 (3.67)	1.63 (2.31)	2.51 (1.84)
Household labour (H_{LABOUR})	1.26 (3.22)	-1.50 (3.89)	-2.17 (2.43)	-2.85 (1.96)
Dependency ratio (H_{DEPEND})	3.18 (13.43)	-7.40 (16.86)	-7.51 (10.86)	-14.22 (9.12)
Tropical Livestock Unit per person (H_{TLUCP})	-1.32 (2.89)	-1.54 (3.30)	0.88 (2.20)	0.93 (1.67)
Annual gross income per person ($H_{GROSSINCCP}$)	-8.06E-06 (5.02E-05)	-3.66E-05 (4.22E-05)	-1.70E-05 (3.50E-05)	-9.39E-06 (2.15E-05)
Total farm land holdings ($H_{HOLDINGS}$)	0.12 (0.35)	-0.12 (0.33)	-0.20 (0.27)	0.13 (0.20)
Plot variables				
Plot distance from homestead (P_{DHOUSE})	-1.78E-04 (5.57E-04)	-8.10E-04 (7.25E-04)	-1.28E-03** (5.80E-04)	-5.87E-04 (3.89E-04)
Plot size (P_{AREA})	-1.73 (1.06)	-14.42*** (4.48)	-3.77** (1.48)	-0.67 (0.56)
Previous crop on the plot ($P_{CROPHIST}$)	-1.54 (1.25)	21.71 (0.00)	6.72** (2.67)	-0.24 (0.71)
Plot upslope ($P_{UPSLOPE}$)	-4.00E-06 (3.53E-06)	-4.59E-07 (7.89E-07)	1.99E-07 (8.00E-07)	5.10E-07 (3.49E-07)
Plot wetness index ($P_{WETNESS}$)	0.12 (0.13)	0.25 (0.16)	-0.07 (0.12)	-0.07 (0.09)
Slope length of the plot (P_{LS})	-0.11 (0.51)	-4.53E-03 (0.40)	-0.33 (0.38)	-0.04 (0.25)
Household access to enabling policy				
Access to credit (H_{CREDIT})	0.14 (1.42)	1.63 (1.38)	1.92* (1.16)	1.08 (0.77)
Fitness and accuracy assessment of the model				
Likelihood ratio test	Chi-square= 171.86;	df=60;	p=0.000	
Pseudo r^2	=0.73 (Cox ad Snell); =0.77 (Nagelkerke); =0.42 (McFadden)			
Area under ROC Curve	=0.81 (Sorghum or millet); =0.90 (Groundnuts); =0.95 (Rice); =0.90 (Maize); =0.84 (Cotton)			

Note: Signs ***, **, and * indicate statistical significance at the 99%, 95%, and 90% levels, respectively.

3.2.2. Common drivers of nutrient management practices adoption

Common drivers of mineral nutrient adoption

Different socio ecological variables determined the decision to adopt the use of mineral nutrient by smallholder farms. The household variables Household head education years (H_{HEDUYR}) and Household size (H_{SIZE}) were common factors that positively affected the probability of adopting mineral fertilizers (Table 6). Households' heads with more years of classic education were more likely to adopt mineral fertilizer in the case of whole population, ALS type 1 and ALS type 3. However large family (H_{SIZE}) were more likely to adopt mineral fertilizer use in the case of whole population only. This variable was not significant when the model was run for separate ALS types. Plot variables that were common driverswere: Plot size (P_{AREA}), Crop type on the plot ($P_{CROPTYPE}$), Plot upslope ($P_{UPSLOPE}$) and Plot wetness index ($P_{WETNESS}$) (Table 6). $P_{AREA,}$ $P_{CROPTYPE}$ and $P_{UPSLOPE}$ augmented the probability of mineral fertilizer adoption for whole population and for all ALS types. This means that farmers were more likely to adopt mineral fertilizer when the plot was large or had large upslope contributing area and when the crop grown was a nutrient demanding crop (i.e. maize, rice or cotton). $P_{WETNESS}$ reduced the adoption of mineral fertilizer for whole population, ALS types 1 and 2. This is understandable since the wettest plots are situated at low slope (inland or foot slope) receiving therefore more sediments and likely considered by farmers as more fertile lands.

Common drivers of organic nutrient adoption

Only plot level variables were found to common drivers of organic nutrient adoption (Table 7). These variables were Plot distance from homestead (P_{DHOUSE}) and Crop type grown on the plot ($P_{CROPTYPE}$). P_{DHOUSE} negatively affected organic nutrient adoption for whole population and for all separate ALS types, meaning that farmers were less likely to adopt organic mineral use for plot remoted from household homestead. On the contrary, $P_{CROPTYPE}$ positively affected the adoption of organic nutrient (Table 7). It indicates that farmers are more likely to adopt organic nutrient use on a plot when the crop grown on that plot is a nutrient demanding crop (i.e. rice, maize or cotton).

Table 6. Adoption of mineral nutrient use by whole population and individual agro ecological livelihood systems

Variable		Coefficients (Odds Ratio)			
		Whole Sample (n=480)	ALS type 1 (n=151)	ALS type 2 (n=190)	ALS type 3 (n=139)
Constant		-3.27 (3.8E-02)	-3.52 (2.9E-02)	-3.74 (2.4E-02)	-8.67 (1.7E-04)
<u>*Household variables*</u>					
Age of household head ($H_{HEADAGE}$)		-0.01 (1.0)	-0.01 (1.0)	0.02 (1.0)	-0.02 (1.0)
Household head education years (H_{HEDUYR})		0.16*** (1.2)	0.32* (1.4)	0.14 (1.1)	0.24* (1.3)
Household size (H_{SIZE})		0.53* (1.7)	0.09 (1.1)	-0.91 (0.4)	0.35 (1.4)
Household labour (H_{LABOUR})		-0.49 (0.6)	0.24 (1.3)	0.94 (2.6)	-0.11 (0.9)
Dependency ratio (H_{DEPEND})		-2.05 (0.1)	-0.31 (0.7)	2.92 (18.6)	0.76 (2.1)
Tropical Livestock Unit per person (H_{TLUCP})		0.16 (1.2)	-8.63* (1.8E-04)	0.48 (1.6)	0.07 (1.1)
Annual gross income per person ($H_{GROSSINCCP}$)		2.25E-06 (1.0)	-5.81E-06 (1.0)	-2.20E-05 (1.0)	3.01E-05* (1.0)
Total farm land holdings ($H_{HOLDINGS}$)		-0.05 (1.0)	-0.76*** (0.5)	0.32*** (1.4)	-0.12 (0.9)
<u>*Plot variables*</u>					
Plot distance from homestead (P_{DHOUSE})		1.66E-05 (1.0)	1.98E-04 (1.0)	-4.46E-04 (1.0)	2.23E-04 (1.0)
Plot size (P_{AREA})		0.92*** (2.5)	2.47*** (11.8)	1.42** (4.1)	1.30** (3.7)
Crop type grown on the plot ($P_{CROPTYPE}$)		3.92*** (50.3)	5.32*** (204.2)	4.47*** (87.7)	4.85*** (127.9)
Plot upslope ($P_{UPSLOPE}$)		2.42E-07* (1.0)	6.73E-07 (1.0)	1.14E-06* (1.0)	-2.97E-09 (1.0)
Plot wetness index ($P_{WETNESS}$)		-0.08** (0.9)	-0.11** (0.9)	-0.15** (0.9)	-0.10 (0.9)
Slope length of the plot (P_{LS})		-0.14 (0.9)	-0.15 (0.9)	-0.02 (1.0)	-0.65** (0.5)
<u>Household access to enabling policy</u>					
Access to credit (H_{CREDIT})		0.14 (1.2)	-2.39*** (0.1)	2.21*** (9.1)	0.30 (1.4)
Fitness and accuracy of models					
Likelihood ratio test	chi-2 (8)	206.07	85.46	115.37	71.27
	P >chi-2	0.000	0.000	0.000	0.000
Nagelkerke Pseudo R^2		0.48	0.63	0.62	0.56
Correct prediction (%)		78.13	86.75	81.01	84.89
Hosmer-Lemeshow test	chi-2 (8)	4.30	2.71	7.98	9.42
	P >chi-2	0.83	0.95	0.44	0.05
Area under ROC curve		0.86	0.93	0.91	0.90

Note: Symbols *, **, and *** indicate statistical significance at 10%, 5, and 1% respectively

Table 7. Adoption of organic nutrient use by whole population and individual agro ecological livelihood systems

Variable		Coefficient (Odds ratio)			
		Whole Sample (n=480)	ALS type 1 (n=151)	ALS type 2 (n=190)	ALS type 3 (n=139)
Constant		-2.94 (0.1)	-2.47 (0.1)	0.74 (2.1)	-32.48 (7.8E-15)
Household variables					
Age of household head ($H_{HEADAGE}$)		0.02 (1.0)	0.02 (1.0)	-0.01 (1.0)	0.07 (1.1)
Household head education years (H_{HEDUYR})		-0.02 (1.0)	0.07 (1.1)	-0.19* (0.8)	-0.95* (0.4)
Household size (H_{SIZE})		0.12 (1.1)	1.29 (3.6)	-0.17 (0.8)	-2.24 (0.1)
Household labour (H_{LABOUR})		-0.18 (0.8)	-1.47 (0.2)	-0.13 (0.9)	3.22 (25.1)
Dependency ratio (H_{DEPEND})		0.64 (1.9)	-5.76 (0.0)	1.76 (5.8)	14.99 (3233990.3)
Tropical Livestock Unit per person (H_{TLUCP})		0.37 (1.5)	7.35* (1555.6)	-0.41 (0.7)	0.02 (1.0)
Annual gross income per person ($H_{GROSSINCCP}$)		-2.57E-06 (1.0)	-1.06E-05 (1.0)	-1.96E-05 (1.0)	1.22E-04** (1.0)
Total farm land holdings ($H_{HOLDINGS}$)		-0.09 (0.9)	-3.04E-03 (1.0)	-0.24 (0.8)	-0.37 (0.7)
Plot variables					
Plot distance from homestead (P_{DHOUSE})		-1.54E-03*** (1.0)	-1.28E-03** (1.0)	-1.51E-03*** (1.0)	-0.01*** (1.0)
Plot size (P_{AREA})		0.48 (1.6)	1.13 (3.1)	-1.55 (0.2)	2.68 (14.6)
Crop type grown on the plot ($P_{CROPTYPE}$)		2.01** (7.4)	1.99** (7.3)	3.17*** (23.9)	5.20*** (181.3)
Plot upslope ($P_{UPSLOPE}$)		-4.47E-07 (1.0)	-4.26E-07 (1.0)	-8.97E-07 (1.0)	-1.21E-06 (1.0)
Plot wetness index ($P_{WETNESS}$)		0.01 (1.0)	-0.16 (0.9)	0.11 (1.1)	-0.05 (1.0)
Slope length of the plot (P_{LS})		0.07 (1.1)	0.17 (1.2)	0.16 (1.2)	-0.40 (0.7)
Household access to enabling policy					
Access to credit (H_{CREDIT})		-0.31 (0.7)	0.90 (2.5)	-0.63 (0.5)	-0.51 (0.6)
Fitness and accuracy of models					
Likelihood ratio test	chi-2 (8)	93.86	34.59	65.79	50.81
	P >chi-2	0.000	0.003	0.000	0.000
Nagelkerke Pseudo R^2		0.32	0.36	0.50	0.62
Correct prediction (%)		85.42	87.42	85.79	92.08
Hosmer-Lemeshow test	chi-2 (8)	19.73	6.24	3.24	1.77
	P >chi-2	0.011	0.621	0.919	0.987
Area under ROC curve		0.84	0.84	0.91	0.89

Note: Symbols *, **, and *** indicate statistical significance at 10%, 5, and 1% respectively

Common drivers of combined mineral-organic nutrient adoption

One household variable ($H_{HEADAGE}$) and three plot variables (P_{DHOUSE}, $P_{CROPTYPE}$ and P_{LS}) were common drivers of combined mineral-organic nutrient (Table 8). Age of household head ($H_{HEADAGE}$) was significant only for whole population and had a positive effect on the adoption of combined mineral-organic nutrient use. It indicates that farms with aged household heads are more likely to adopt the combined mineral-organic nutrient used on the plot, probability due to their experience of the positive of this practice on soil fertility in the short and medium term. Like in the case of organic nutrient, Plot distance from homestead (P_{DHOUSE}) reduced the chance for farmer to adopt combined mineral-organic nutrient use on a plot. Crop type grown on the plot ($P_{CROPTYPE}$) positively affected the adoption of combined mineral-organic nutrient (Table 8). It shows that farmers are more likely to adopt combined mineral-organic nutrient use on a plot when the crop grown on that plot is a nutrient demanding crop (i.e. rice, maize or cotton) to reduce mineral nutrient cost and benefit from the combined effect of these nutrients. Surprisingly Slope length of the plot (P_{LS}) also reduced the probability of combined mineral-organic adoption (Table 8). Given that slope length may indicate soil erosion risk it was expected P_{LS} to increase the probability of combined mineral-organic nutrient. The observed affecting direction of P_{LS} can be explained by the fact that due to erosion risk the plot, the farmer chooses to grown a less nutrient demanding crop (sorghum or millet) or even a nutrient fixing crop (legume crops like groundnuts).

Table 8. Adoption of combined mineral-organic nutrient use by whole population and individual agro ecological livelihood systems

		Coefficient (Odds ratio)			
		Whole Sample (n=480)	ALS type 1 (n=151)	ALS type 2 (n=190)	ALS type 3 (n=139)
Constant		-4.94 (7.16E-03)	-3.17 (4.2E-02)	-24.28 (2.84E-11)	-32.19 (0.0)
<u>Household variables</u>					
Age of household head ($H_{HEADAGE}$)		0.03** (1.0)	0.03 (1.0)	0.01 (1.0)	0.05 (1.1)
Household head education years (H_{HEDUYR})		0.08 (1.1)	0.22 (1.2)	0.03 (1.0)	-0.95* (0.4)
Household size (H_{SIZE})		0.75 (2.1)	4.10* (60.1)	-0.34 (0.7)	-6.39* (0.0)
Household labour (H_{LABOUR})		-0.80 (0.5)	-4.26* (1.4E-02)	0.58 (1.8)	7.62* (2037.8)
Dependency ratio (H_{DEPEND})		-1.83 (0.2)	-18.62 (8.2E-09)	3.01 (20.2)	37.49** (1904.0)
Tropical Livestock Unit per person (H_{TLUCP})		1.17 (3.2)	0.04 (1.0)	2.71 (15.0)	-1.28 (0.3)
Annual gross income per person ($H_{GROSSINCCP}$)		-3.41E-07 (1.0)	-4.97E-06 (1.0)	-2.09E-05 (1.0)	1.33E-04** (1.0)
Total farm land holdings ($H_{HOLDINGS}$)		-0.06 (0.9)	-0.27 (0.8)	0.10 (1.1)	-0.73* (0.5)
<u>Plot variables</u>					
Plot distance from homestead (P_{DHOUSE})		-1.65E-03*** (1.0)	-8.13E-04 (1.0)	-3.10E-03* (1.0)	-3.54E-03** (1.0)
Plot size (P_{AREA})		0.57 (1.8)	3.79** (44.4)	-0.77 (0.5)	2.38 (10.8)
Crop type grown on the plot ($P_{CROPTYPE}$)		2.56*** (13.0)	7.48** (1774.2)	18.42 (9972.4)	4.87*** (130.9)
Plot upslope ($P_{UPSLOPE}$)		-6.51E-07 (1.0)	8.22E-07 (1.0)	-1.05E-06 (1.0)	-3.42E-06 (1.0)
Plot wetness index ($P_{WETNESS}$)		-0.04 (1.0)	-0.73** (0.5)	0.15 (1.2)	-0.15 (0.9)
Slope length of the plot (P_{LS})		-0.56* (0.6)	-1.64* (0.2)	-0.03 (1.0)	-2.63* (0.1)
<u>Household access to enabling policy</u>					
Access to credit (H_{CREDIT})		-0.21 (0.8)	-1.12 (0.3)	2.12 (8.4)	1.39 (4.0)
Fitness and accuracy of models					
Likelihood ratio test	chi-2 (8)	67.15	42.41	37.21	39.86
	P >chi-2	0.000	0.000	0.001	0.000
Nagelkerke Pseudo R^2		0.32	0.56	0.47	0.59
Correct prediction (%)		92.90	92.72	94.74	92.81
Hosmer-Lemeshow test	chi-2 (8)	1.28	2.74	3.58	1.54
	P >chi-2	0.996	0.949	0.893	0.992
Area under ROC curve		0.86	0.96	0.93	0.96

Note: Symbols *, **, and *** indicate statistical significance at 10%, 5, and 1% respectively

3.3. Livelihood type-specific drivers

3.3.1. Livelihood type-specific drivers of crop choice

Livelihood type-specific drivers of *groundnuts crop choice*

The variables Household head education years (H_{HEDUYR}), Tropical Livestock Unit per person (H_{TLUCP}), Access to credit (H_{CREDIT}) were drivers specific to ALS1 (Table 3). They were not significant for other ALS types and for whole population. Only H_{TLUCP} was also significant for whole population but with lower amplitude of the coefficient (18.17 in the case of ALS 1 against 0.72 in the case of the whole population). Educated farm head have more chance to choose groundnut crop only when they belong to ALS 1. The fact that the number of tropical units increases the chance of choosing groundnuts by farmers may indicate a beginning of crop-livestock integration since education also increases the probability of groundnuts choice by farmers of this ALS type. The Age of household head ($H_{HEADAGE}$) and Previous crop on the plot ($P_{CROPHIST}$) were specific drivers of groundnuts crop choice by ALS 2. They both reduced the probability of groundnuts crop choice. $P_{CROPHIST}$ was significant for whole population but with lower amplitude.

Livelihood type-specific drivers of *rice crop choice*

The Age of household head ($H_{HEADAGE}$) was found significant for rice crop choice for only ALS 1 (Table 3 - table 5). Aged household heads tend to choose rice crop instead of "sorghum or millet" crops when they belong to ALS 1. When Previous crop on the plot ($P_{CROPHIST}$) is nutrient demanding crop (Maize or cotton) farmers of ALS 2 have more chance for choosing rice crop instead of "sorghum or millet" crops (Table 4). The variable Slope length of the plot (P_{LS}) appeared significant for rice crop choice by farmers of ALS 2 only (Table 4). This variable which indicates soil erosion risk and low wetness potential reduces the probability of growing rice on a plot compared to "sorghum or millet" crops which are more water stress resistant and less nutrient demanding.

Livelihood type-specific drivers of *maize crop choice*

The M-Logit results showed only one livelihood type-specific affecting factor for maize crop choice (Table 5). In effect the variable Access to credit (H_{CREDIT}) was statistically significant for maize crop choice by farmers of ALS 3 only. The access to credit increased the probability of maize crop choice by these farmers.

Livelihood type-specific drivers of *cotton crop choice*

Variables that significantly determined the probability of cotton crop choice were specific to the different agricultural livelihood system (ALS) types. For ALS 1, the choice of cotton crop was negatively influenced by the age of the household head ($H_{HEADAGE}$) (Table 3). Households of ALS 1 headed by old persons had more chance of choosing "sorghum or millet" crops instead of cotton crop. The ALS 1 comprises subsistence-based farms and the fact that old heads may be risk averse may lead them to prioritize filling food gap by producing subsistence crops rather than cash crop. As for ALS 2, negative and specific influencing factors were found as well as positive and specific influencing factors (Table 4). Household labour (H_{LABOUR}), Dependency ratio (H_{DEPEND}), Tropical Livestock Unit per person (H_{TLUCP}) and Access to credit (H_{CREDIT}) augmented the probability of choosing cotton crops by farmers. However, Plot distance from homestead (P_{DHOUSE}) and Slope length of the plot (P_{LS}) reduced the probability of choosing cotton crop by farmers of ALS 2. This suggests that farmers tend to allocated cotton to non-remoted and to good lands that are less vulnerable to soil erosion. This is understandable in the sense that cotton crop supposed the use of nutrient resources (organic or mineral) which transportation may be difficult for remote plots. Also, cotton is labour intensive, especially the harvest. Plot remoteness from household may limit the participation of some household members (women, children and aged people) to cotton farming activities. For the ALS 3 (Table 5) only one livelihood type-specific affecting factor was found. Indeed, the Household head education years (H_{HEDUYR}) negatively affected the probability of cotton crop choice by farmers. Wealthy household farms headed by educated people have low probability of choosing cotton crop compared to "sorghum or millet" crops.

3.3.2. Livelihood type-specific drivers of nutrient management practices adoption

Livelihood type-specific drivers of mineral nutrient adoption

The variables Tropical Livestock Unit per person (H_{TLUCP}) and Annual gross income per person ($H_{GROSSINCCP}$) were affecting factor of mineral nutrient adoption specific to ALS type 1 and ALS type 2, respectively (Table 6). H_{TLUCP} had a negative effect and therefore reduced the chance of adopting mineral nutrient use by ALS type 1 which was the less endowed farm type. $H_{GROSSINCCP}$ had a positive effect on mineral nutrient adoption by farms of ALS type 3. This means that the income per person increase the chance for farmers to adopt mineral nutrient use. Mineral in sub-Saharan African countries are usually costly and high prices limit the purchase of mineral nutrient. Therefore a better income is likely contributes to improve mineral fertilizer acquisition. Total farm land holdings ($H_{HOLDINGS}$) was significant for ALS type 1 and ALS type 2 but was considered as type–specific due to the fact it affecting direction was different for the two ALS types (Table 6). $H_{HOLDINGS}$ negatively affected mineral nutrient adoption for ALS type 1 while it positively affected the adoption for ALS type 2. This indicates that large holdings lands reduces the chance mineral nutrient adoption by ALS type 1. This farm type being the least endowed is likely to be unable to afford purchasing mineral fertilizer for large farm lands. On the contrary, the variable land holding is likely to increase the chance of mineral nutrient adoption by ALS type 2. This farm type is a medium income farm type. It is therefore more endowed than ALS type 2. It may have better access to mineral fertilizer. Moreover, this can be explained by the fact that ALS type 2 is cotton-based. A cotton credit system in the region allows cotton producers to have access to mineral fertilizer. This argument is supported by the household access to enabling policy variable, Access to credit (H_{CREDIT}). Indeed, results showed that H_{CREDIT} is a type specific affecting variable. It had a positive effect on mineral adoption by ALS 2 while it had a negative effect on mineral nutrient adoption by ALS type 1.

The results also showed existence of plot variables that were type specific affecting factors. In effect, Plot upslope ($P_{UPSLOPE}$) was significant for ALS type 2 only and for whole population (Table 6). It had a positive effect of the probability of mineral fertilizer adoption, meaning that large upslope contributing area is likely to increase the probability for the farm to adopt mineral nutrient use on a plot. Slope length of the plot (P_{LS}) had a negative effect on mineral nutrient adoption by ALS type 3. It indicates that a large value of the slope length is likely to reduce mineral nutrient adoption by farms of ALS type 3. Due to erosion risk on plots with lengthy slope, farms could be expected to adopt mineral nutrient. The fact that the slope length reduced the chance of mineral nutrient adoption can be explained by farms allocating plots with lengthy slope to legume crops like groundnuts or to less nutrient demanding crops like sorghum or millet.

Livelihood type-specific drivers of organic nutrient adoption

Type specific drivers of organic nutrient adoption were exclusively household variables (Table 7). Household head education years (H_{HEDUYR}) had a negative effect on organic nutrient adoption by ALS type 2 and ALS 3. This indicated that farms with educated household head are likely to not adopt organic nutrient. These farms types are middle class and best endowed and are cotton-based. They benefit from mineral fertilizer credit given by cotton companies. Given this credit system and the fact that organic fertilizer require additional labour, farmers may tend to produce and use less organic nutrient. This argument is supported by results in Table 6 showing that H_{HEDUYR} positively affect mineral adoption by ALS type 3. Tropical Livestock Unit per person (H_{TLUCP}) was significant for ALS type 1 only. It had a positive effect meaning that farms of ALS type 1 (poor and subsistence-base farms) are likely to adopt organic nutrient use when their livestock increases. The variable Annual gross income per person ($H_{GROSSINCCP}$) affected the probability of organic nutrient adoption by ALS type 3 only. It has a positive effect indicating that farms of ALS type 3 are likely to adopt organic nutrient when their income increases.

Livelihood type-specific drivers of combined mineral-organic nutrient adoption

Most type specific variables affecting the adoption of combined mineral-organic nutrient use by farms were household variables. Household size (H_{SIZE}) had a positive effect on the probability of adopting combined mineral-organic nutrient use by ALS type 1 and a negative effect for ALS type 3 (Different affecting direction). This means that while a large family increases the chance for farms of ALS type 1 to adopt combined mineral-organic nutrient, it decreases the chance of adoption by ALS type 3. Household labour (H_{LABOUR}) also had different affecting direction for ALS type 1 and ALS type. It had a negative effect on the adoption of combined mineral-organic nutrient by ALS type 1 but a positive effect in the case of ALS type 3. This indicates that labour may be a constraint for farms of ALS type 3 and it availability increases the chance of adopting combined mineral-organic nutrient use by these farms. The Dependency ratio (H_{DEPEND}) indicating the number of non-active people per worker of the household had a positive effect on the adoption of combined mineral-organic nutrient use by farms of type 3 only. This means that when this ratio is high (low number of workers) the farm tend to adopt the combined mineral-organic nutrient use to boost crop productivity. Indeed, previous studies (Kearney *et al.*, 2012; Kismányoky and Tóth, 2012) showed that combined mineral-organic nutrient use generate better yield than sol mineral or organic fertilize use only. The variables Annual gross income per person ($H_{GROSSINCCP}$) and Total farm land holdings ($H_{HOLDINGS}$) respectively had a positive and negative effect on combined mineral-organic nutrient use by farms of ALS type 3. This indicates that the level of income of the farm increases the chance of adopting combined mineral-organic nutrient while large land holding reduces this chance.

Two plot variables were identified as type specific drivers of combined mineral-organic nutrient adoption. Plot size (P_{AREA}) had a positive on the probability of combined mineral-organic nutrient adoption by farms of ALS type 1 while Plot wetness index ($P_{WETNESS}$) had a negative effect. This means that large plot size compels the farms to adopt combined mineral and organic nutrient use given their poverty and limited access to mineral nutrient. However, plot wetness is likely to reduce the probability of combined mineral-organic nutrient adoption by farms of ALS type 3.

4. Discussion

4.1. Contextualization of main findings

The study analyzed drivers of crop choice and of nutrient management practices adoption at plot level by heterogeneous agro ecological livelihood types in a dryland area. The results showed that household variables (human and financial assets), plot variables (natural and physical assets) as well as household enabling policies determined crop choice (Le, 2005; Yilma and Berger, 2006; Ayele *et al.*, 2015) and nutrient management adoption (Kassie *et al.*, 2013; Martey *et al.*, 2014; Thiombiano, 2015). The main significant drivers for both crop choice model and nutrient management adoption model were Household head age and his education, household size, Plot distance from household homestead, plot size, crop history on the plot and household enabling policies. The results demonstrate the need for including these variables as key variables for rigorously modeling crop choice and nutrient management in the study region and in similar dryland areas. The study also demonstrates the linkage between crop choice decision making and nutrient management adoption. Indeed, the variable Crop history significant for both crop choice and nutrient management adoption models denotes the residual fertility due to previous crop choice which not only depends on the previous nutrient management on the plot but will further determine the current nutrient management practice.

For both crop choice and nutrient management models, drivers varied across agro ecological livelihood system types in different ways: (i) in nature, as a driver may not be significant across all livelihood system types but only for some livelihood system types;

(ii) in direction, as for instance a driver may have a positive effect in the case of a given livelihood system type while having a negative effect for another livelihood system type; (iii) and in amplitude, as the effect of a drivers for a given livelihood system type may be stronger or weaker than for another livelihood system type. This is named responsive heterogeneity. It was first mentioned by Le(2005) and later deepen by the research of Thiombiano and Le (2015a; Submitted). The responsive heterogeneity highlights the existence of common drivers and livelihood system specific drivers.

Most crop choice (Yilma and Berger, 2006; Ayele *et al.*, 2015) and nutrient management studies (Chianu and Tsujii, 2005; Marenya and Barrett, 2007; Mugwe *et al.*, 2008; Kassie *et al.*, 2013) focused on analyzing the behavior of the whole population only. However, in reality all different farm types of a same population do not behave the same way due to their livelihood heterogeneity which generates responsive heterogeneity. An analysis based on whole population results and ignoring individual farm type results will certainly miss emergent factors and therefore lead to inefficient interpretation and inappropriate intervention. Livelihood system type-specific effect is not captured. This limits the understanding of farmers' behavior and thereby the efficiency of intervention and the performance of farm design studies.

4.2. Added value of the study, implication for policy intervention and farming design

The study makes an important contribution to studies in the study region in particular and to farming systems studies in general:

i) The results demonstrated that the difference amongst studied agricultural livelihood types does not reside only in their structure (Thiombiano and Le, 2015b) in terms of assets endowment (i.e. land, livestock and labour). It reveals that the agro ecological livelihood system types also differ in their decision making, i.e. the way they function. The typology is therefore a structural and functional typology.
ii) Following the work of Thiombiano and Le (2015a; Submitted) on responsive heterogeneity in nutrient management adoption, the present study confirms their finding and extends the research to crop choice (land use) decision making. This gives an important insight into farm behavior since crop choice and nutrient management decision making are the backbone of the farming system that any design study should apprehend.

iii) The study analyzed both crop choice and nutrient management decision making and pointed out their linking.

iv) The results of the study demonstrate the key importance of considering farm responsive heterogeneity of different livelihood system types in better understanding the decision making operated by farmers. It is useful for efficiently formulating interventions and for farm design studies. The results of the present study can serve as a framework scaling-out research and for studies in the study region and in similar drylands areas. These results are also very useful for agent-based modelling of Agricultural Livelihood Systems.

4. Conclusion

The smallholder farming system sustainability is at stake and mobilizes farming research for proposing innovative pathways. The support to the transition of Agricultural Livelihood System in dryland areas poses the need of better sizing actual farming system structure and functioning. The present study succeeded in clearly identifying main factors influencing factors of crop choice and nutrient management decision making by the main Agro ecological Livelihood Systems (ALS) types in the village of Pontieba. The main biophysical drivers related to household settings (household head education and age, household size), plot settings (Plot area, slope, upslope and distance from household homestead) and to enabling policy. These factors varied across the ALS types revealing the existence of responsive heterogeneity for crop choice and confirming it for nutrient management practices adoption. The study demonstrated the important role of livelihood heterogeneity in farm behaviour and the need for considering the resulting responsive heterogeneity. The study also proved that the used typology is structural and functional with regards to crop choice and land-use decision making. It demonstrated the key importance of accounting for responsive heterogeneity. It provides useful information for farming design studies, policy intervention, and moreover for agent-based modelling of smallholder Agricultural Livelihood Systems.

5. The ways forward

This study conducted in the frame of a research aiming at modelling Agricultural Livelihood Systems in the village of Pontieba by adapting the agent-based model LUDAS developed by Le (2005). The study follows a previous study that formulated Agricultural Livelihood System typology in Pontieba. It used the identified typology to model land-use choice making by each Agricultural Livelihood System in Pontieba. The next step of the research will be:

- To Analysing yield function of main crops and livestock;
- Performing the agent-based modelling of the agricultural livelihood systems in Pontieba by adapting the LUDAS model (Le *et al.*, 2008; Le *et al.*, 2010a; Le *et al.*, 2010b; Le *et al.*, 2012).

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