Support building resilient smallholder farms to climate change: I. Livelihood profile and nutrient management in the Loba province, Burkina Faso

Alexandre Boundia Thiombiano[1,2] and Quang Bao Le[3]

[1] *Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. Corresponding author. E-mail: boundia@gmail.com*

[2] *West African Science Service Center on Climate Change and Adapted Land Use (WASCAL)*

[3] *Natural and Social Science Interface (NSSI), Institute for Environmental Decisions (IED), Swiss Federal Institute of Technology (ETH-Zurich), Zurich, Switzerland*

Abstract: Climate change through increasing aridity disrupts nutrient cycles which are the basis of food production in agro ecosystems. Existing production systems in West Africa fail in maintaining a good enough nutrient cycling at farm level. Adaptation of smallholders to climate change requires rethinking and adjusting their existing production systems in order to improve their nutrient balance and to ensure an efficient provision of food demand. They need to be supported in this way with open decision-making tools (agent-based model) based on nutrient cycling and accounting for feedback loops. Adaptation capacities depend mainly on livelihood assets endowment. Our project in the Ioba province, starts by identifying livelihood profiles of smallholders and their link to the actual nutrient management. Three communities of the province were chosen through a cluster analysis using NDVI index, land use map, soil degradation information, and population density. Using soil map, six villages were randomly selected and 360 farms were surveyed. Five farm-types were found: Better-off, cotton-and livestock-based farms (Farm-type I); Better-off, non-farm activities preference farms (Farm-type II); Pro-poor, labourless-and landless farms (Farm-type III); Medium income, labour-rich, marketable food crop oriented and educated farms (Farm-type IV); and Poor, insecure-land tenure, livestock based farms (Farm-type V). Existing fertility management strategies are linked to farm's wealth, livelihood orientation, land access, labour availability and supporting policies. Better-off farm-types intensify fertilizer use with livelihood orientation and supporting policies while less endowed farm-types (III and V) intensify fertilizer use with land constraint.

Keywords: Climate change, Adaptation, Smallholder agro-ecosystem, Burkina Faso, Agent-based modelling

Introduction

Climate change and its impact on farming activities are a growing issue through the world. Many research activities have been conducted on how farmers can adapt to these changes. A clear outcome of this research is that farmers should reassess their farming practices to be able to adapt to persistent climate change. Modelling is a useful tool for guiding farmers' decision making. Many models and tools have then been built to serve this purpose (McCown et al., 1995; McCown et al., 1996; De Jager et al., 1998; Van den Bosch et al., 1998; Belcher et al., 2004; Matthews, 2006). However, there still is the need for open nutrient cycle-based models for applying farmers' system design options of farm structure, accounting for decision making and including feedback loops.

In effect, farm production depends on the performance of the nutrient cycle threatened by climate change. With increasing climate variability farmers must be capable of quick adaptation responses. To be capable of quick adaption behaviour farmers should be continuously adjusting their strategies to maintain good enough nutrient balance. They must consider shifting from one management mode of their farm to another along with the changing environment and available opportunities. Feedback loops existing in a system, here the farm, are key for understanding and evaluating the adaptation capacity of the system. Through the feedback loop system, the human agent perceives the environmental status, reacts to it, transforms the environment with a retroactive effect on the decision-making process in itself and of other agents in a short-term fashion (Le *et al.*, 2012).

Below *et al.* (2010) highlight that adaptation is highly context sensitive. Beyond the environmental context it requires considering the livelihood assets endowment of farms (land, financial resources, skills, technologies, etc.). A farm might be well endowed in one asset but poor in another and the type of poverty can influence the environment-poverty links (Reardon & Vosti, 1995). With the same logic, the type of asset poverty makes difference in human-environment relationship of two farms, and hence their adaptive capacity. Our study used the household livelihood framework (Sconnes, 1998; DFID, 1999; Sherbinin et al., 2008) to identify smallholder farms types in the Ioba province and to characterize their management of nutrients at farm level. This work is the first step of a research project that is aiming at building an actor-oriented feedback loop system model for guiding the option of West African smallholder's adaptation to climate change and moreover their transformation into resilient farms in the face of climate change.

Material and methods

Study sites selection and farms sampling

The study zone is the Ioba province located in the Black Volta Basin, South West Burkina Faso. It lies between 10°42'-11°20'N latitude and 02°36'-03°25' W longitude. The province is part of the South-Sudanian climatic zone. The climate is characterized by two seasons: a rainy season from end of April-May to October and a dry season from November to March-April. The wettest months are August and September while the hottest months are March and April. The average rainfall varies between 900 mm and 950 mm. The province experiences rain variability in time and space (MAHRH & GTZ, 2004). Following biophysical and demographical criteria that influence land use and nutrients use, three communities out of eight were selected to form the study area. On the basis of the two main soil types in the study area, two villages (one per main soil type) were randomly selected per community to serve as study sites. Six villages were randomly selected: Pontieba and Loffing in Dano community, Babora and Dibogh in Koper community, and Kolinka and Bekotenga in Ouessa community. Sixty farms were randomly sampled per village. Farms are represented by their household for the survey. For each village, we used the list of households, as exhaustive as possible. Random sampling was performed within STATA software. In total, 360 of the 1,232 households were sampled (29.22% of total households). The data was collected during dry season 2013 (January-February) using a semi-structured questionnaire which gathered socio-demographic data, geographical data, and information on farms' livelihood.

Method for identifying farm-types

To identify typical farms in the study area, we used a two steps-method: at first a Principal Component Analysis (PCA) and then a K-mean Cluster Analysis (CA). The choice of the entry variables for the Principal Component Analysis (Table 6) was guided by the household sustainable livelihood framework which groups livelihood assets into five main types of capital (Sconnes, 1998 ; DFID, 1999 ; Sherbinin et al., 2008): *Physical capital* (basic infrastructures, tools, and equipment); *Natural capital* (natural resources stock: land, water, air, forest resources, etc.); *Financial capital* (available cash or equivalent: savings, livestock, regular inflow of money such as pension, transfer and remittance, etc.); *Human capital* (knowledge, skills, labour, and capabilities to pursue and achieve livelihood goals. It allows valuing the other assets); and *Social capital* (social networks, membership to organizations or groups).

Table 1: Variables considered in Principal Component Analysis (PCA)

Variable name	Brief definition	Source*
Human capital		
$H_{\text{Age members}}$	Average age of household members	**C**
$H_{\text{Age of the labour}}$	Average age of household labour	**C**
$H_{\text{Head education}}$	Number of education years of the household head	**C**
H_{Size}	Size of the household	**D**
H_{Labour}	Labour amount of the household (workers)	**C**
$H_{\text{Dependency}}$	Dependency ratio of the household	**C**
Natural capital		
$F_{\text{Holding lands}}$	Total land area (ha) the farm possesses	**C**
$F_{\text{Holding per capita}}$	Farm land possession per capita (ha per capita)	**C**
$F_{\text{\% cereal area}}$	Share of cereals within cultivated lands of the farm (%)	**C**
$F_{\text{\% cotton area}}$	Share of cotton within cultivated lands of the farm (%)	**C**
$F_{\text{\% cash crops}}$	Share of cash crops within cultivated lands of the farm (%)	**C**
$F_{\text{\% owned land}}$	Share of owned lands within cultivated lands of the farm (%)	**C**
$F_{\text{\% user right land}}$	Share of user right lands within cultivated lands of the farm (%)	**C**
Physical capital		
$F_{\text{Transport}}$	Number of transport means (Bicycles, motorbike) of the household	**C**
$H_{\text{House equipment}}$	Number of house equipment (Mattress, bed) of the household	**C**
$F_{\text{Traction animals}}$	Number of traction animals the farm possesses	**D**
Financial capital		
$F_{\text{Gross income}}$	Annual gross income of the farm (CFA)	**C**
$F_{\text{Gross income/capita}}$	Annual gross income per capita (CFA per capita)	**C**
$F_{\text{\% crop income}}$	Share of crop income within gross income (%)	**C**
$F_{\text{\% livestock income}}$	Share of livestock income within gross income (%)	**C**
$F_{\text{\% non-farm income}}$	Share of non-farm activities income within gross income (%)	**C**
$F_{\text{\% transfer income}}$	Share of transfer income (pension, gift) within gross income (%)	**C**
F_{TLU}	Tropical Livestock Units of the farm (%)	**C**
$F_{\text{TLU/capita}}$	Tropical Livestock Units per capita (TLU per capita)	**C**
$F_{\text{TLU/ha}}$	Tropical Livestock Units per unit of cultivated land (TLU ha^{-1})	**C**
Geographical variables		
$H_{\text{Distance paved road}}$	Average distance of the household to paved road (km)	**R**
$H_{\text{Distance main town}}$	Average distance of the household to main town (km)	**R**

***D**= Direct extracted from the questionnaire; **C**= Compound information calculated based on information coded in the questionnaire; **R**= Extracted from map reading.

Analysing farm-type soil fertility management

Soil fertility management strategies in use by farms are the result of decision making, given their knowledge and the information their perceived from their environment (within farm, neighbourhood, etc.). Analysis of this management is done through descriptive statistics of data collected during the surveys.

Results and discussions

Livelihood based typology of the farms

The scores of principal components (10) with Eigen value greater than or equal to one were used to run the K-mean cluster analysis with the Knee method as decision method for the number of clusters. Five optimal classes were found. The livelihood dimension structure shown by the radar diagram constructed using standardized variables (**Fehler! Verweisquelle konnte nicht gefunden werden.**) and the composition of the income helped to characterize the identified farm-types.

Farm-type I: Better-off, cotton-and livestock-based farms. They represent around 31% of study sample. They have highest revenue (109,577 FCFA per capita), and are most endowed in land resources (0.98 ha per capita). Cotton usually requires having enough land; the bigger the cropped area, the higher the profitability of cotton production (PAFASP and CAPES, 2011). Livestock forms the biggest share within annual gross income (nearly 54 %). In the study area and Burkina Faso in general, cotton is regarded as the main non-food cash crop, and livestock is a form of capitalization of financial resources drawn from cotton. Cotton revenue is partly reinvested in livestock that can be sold out and the money used in case of food shortage.

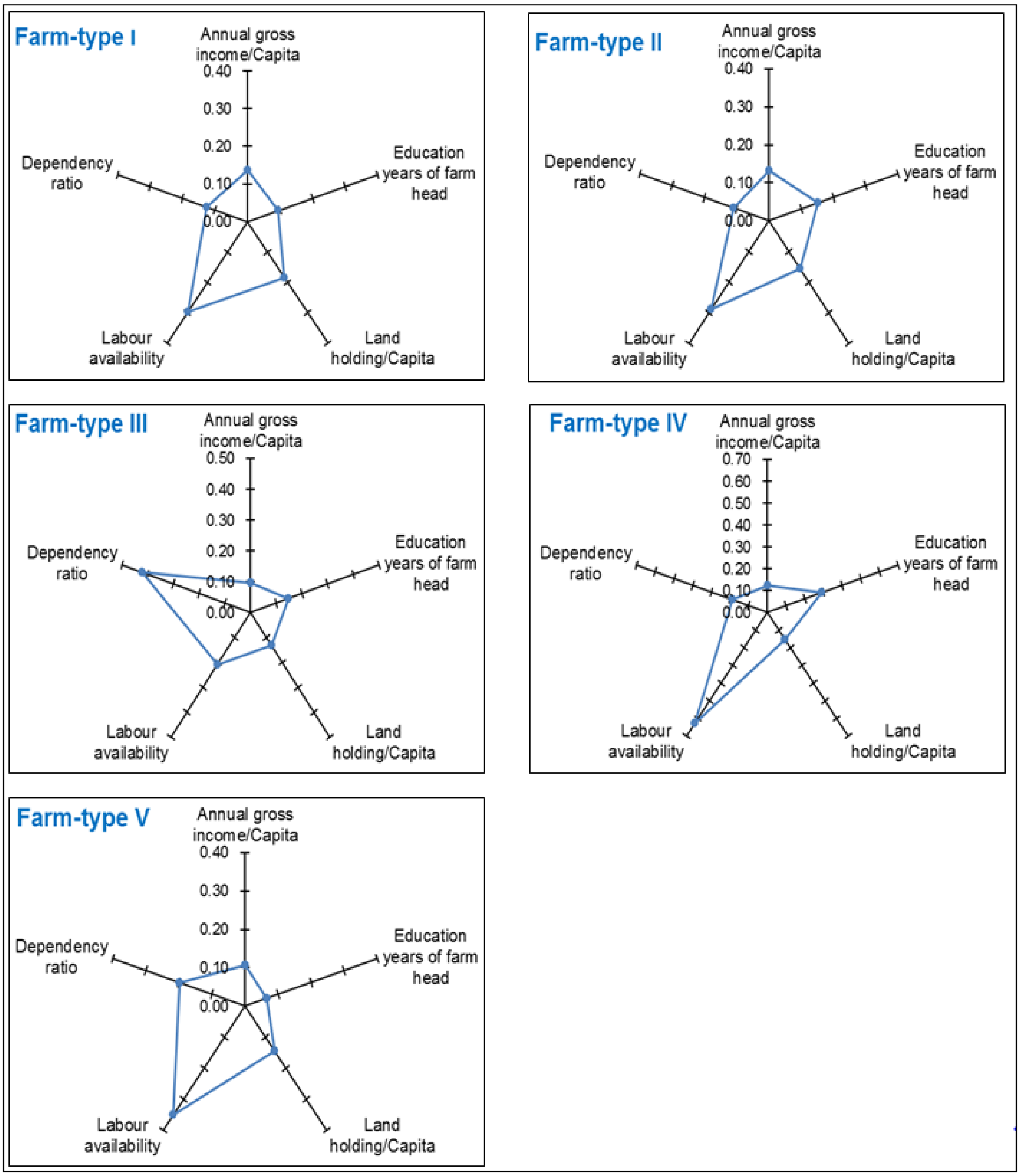
Farm-type II: Better-off, non-farm activities preference farms. They form 30 % of the study sample. They are also among high revenue farms, but have lower gross income per capita compared to the farm-type I (107,343 FCFA per capita). They have the lowest dependency ratio among the five farm-types (0.22) and their head are more educated than those of the farm-type I (1.83 against 1.12 years of classic education for farm-type I). Their main resource is non-farm activities (trade, salary, pension, etc.) which are providing up to 77.32% of annual gross income.

Farm-type III: Pro-poor, labourless-and landless farms. This group represents 21% of the study sample. Its farms have the lowest revenue per capita: 78,236 FCFA per capita. There are characterized by highest dependency ratio (0.84), lowest available labour (4 workers) and lowest land resources (0.72 ha per capita). Livestock forms biggest share within annual gross income.

Farm-type IV: Medium income, labour-rich, marketable food crop oriented and educated farms. This group forms 9% of study sample. Members of this farm-type present medium income compared to the others (101,529 FCFA per capita). They are the most endowed in labour (11 workers in average), have the most educated heads (3.52 years of classic education). A big proportion of their cropping land is allocated to marketable food crops production. These farms appear as farms with most diversified activities and income sources. Contrary to other farm-types, none of their income sources is forming half of annual gross income on its own: livestock forms 44.44 %, the non-farm activities almost 34 % and transfers up to nearly 6 %.

Farm-type V: Poor, insecure-land tenure, livestock based farms, representing 8% of study sample. Their average annual revenue per capita is 86,413 FCA. They are characterized by insecure land tenure for they have in general only user-rights on the lands they are exploiting. The land holding is evaluated to 0.78 ha per capita. The share of livestock within annual gross income is 58.52 %. Their livelihood strategy is built on livestock which mainly exploits common lands for pastures and does not require having necessarily own lands.

Figure 1: Key indicators of livelihood dimensions of the five farm-types



The livelihood-based typology we found is supported by previous studies. Tittonel et al. (2005) found an alike typology in western Kenya: two wealthy classes relying on cash crops and non-farm activities, two diversified middle class farms and one landless poorest farms class. In the Ioba province, but for a different study area comprising three villages, Gleisberg-Geiser (2012) came out with a less detailed typology: she found three farm-types: Diversified farms, Cash-crops oriented farms and Non-farm oriented farms. Our study is thus bringing more insight and precision in the structure of smallholder farms typology of the Ioba province.

Soil fertility management by farm-types

This section is looking at practices and measures farms use in managing their soil fertility: use of mineral fertilizer and conservation agriculture practices (organic fertilization, soil and water conservation technologies).

Mineral fertilization

The fertilizer use intensity expresses the total amount of fertilizer (in Kilograms) used at farm level divided by the total rainfed cropped area (in hectares) of the farm. Table 2 shows average amount of NPK and NPK+Urea used per unit of cropped land. Farm-types I and IV are farms with highest fertilizer use intensities.

Their financial endowment allows them to purchase fertilizer. For farm-type I, comprising biggest cotton producers, there is also the indirect effect of cotton production. In effect it is known that farmers usually divert fertilizer provided by cotton companies (through a credit system) for cropping cotton to cultivate other crops (PAFASP and CAPES 2011). Even though they are better-off farms, farm-type II has lowest fertilizer use intensity (10.28 kg ha^{-1} for NPK and 14.86 kg ha^{-1} for NPK+Urea). This is because of their preference for non-farm activities; in investing they give low priority to agricultural activities. Pro-poor farms (farm-type III) perform better than Poor (farm-type V) and even have fertilizer use intensity close to Farm-type IV. Landless and labourless, they compensate by intensifying fertilizer use; while farm-type V, better endowed in labour can rely on this labour to crop comparatively biggest areas and on manure use from their livestock.

Table 2: Mineral fertilizer use intensity (kg ha^{-1})

Farm-type	Fertilizer	n	$\overline{X}$	σ_X	$S.e_{\overline{X}}$	X_{Min}	X_{Max}	95% CI	
								Lower bound	Upper bound
I	NPK	103	21.21	2.38	24.14	0.00	150.00	16.49	25.93
	NPK+Urea	103	28.96	3.23	32.82	0.00	200.00	22.54	35.37
II	NPK	100	10.28	1.37	13.69	0.00	55.17	7.56	13.00
	NPK+Urea	100	14.86	1.96	19.58	0.00	89.66	10.97	18.74
III	NPK	70	15.91	2.55	21.35	0.00	100.00	10.82	21.00
	NPK+Urea	70	24.59	4.04	33.83	0.00	200.00	16.52	32.65
IV	NPK	28	16.74	2.64	13.98	0.00	60.00	11.32	22.17
	NPK+Urea	28	25.41	3.88	20.54	0.00	80.00	17.45	33.37
V	NPK	27	13.93	3.68	19.10	0.00	69.23	6.37	21.48
	NPK+Urea	27	20.04	5.07	26.35	0.00	92.31	9.62	30.46
Total	NPK	328	15.77	1.10	19.97	0.00	150.00	13.60	17.94
	NPK+Urea	328	22.69	1.58	28.58	0.00	200.00	19.58	25.79

Note:

n: group size (i.e., number of households for each group)

$\overline{X}$ *: Mean value of variable X;* σ_X *: Standard deviation of the mean,*

$S.e_{\overline{X}}$ *: Standard error of the mean;* X_{Min}*: minimal value of variable X,*

X_{Max}*: maximal value of variable X; CI: Confidence interval*

Conservation agriculture

We looked at main conservation agriculture practices in the study area as shown in Table: (i) the recycling of crop residues consisting of re-using crop residues either through composting or ploughing techniques that bury crop residues on the plots; (ii) use of animal dung gathered from the farm's enclosures or from outside farm; (iii) use of stone bunds. Farm-type I, IV and II are those recycling the most their crop residues through composting mainly, with 26.67 %, 24.14 % and 23.53 % of their members using this practice respectively. Beside the fact that composting requires a training to acquire good practices, it also requires having enough labour at disposal to gather crop residues and manure to the compost pit, water the pit and take care of the compost (turning over the compost). If the fact that farm-type IV is better endowed in labour, can explain the high use of composting, farm-types I and II either have good financial resources to hire the labour needed for digging or are big biological cotton producers. In effect, these biological cotton producers benefit from a particular technical assistance of cotton producers union (UNPCB) as to how to perform a good composting.

Farm-types IV and III (Poor and Pro-poor) have the highest proportion of farmers using animal dung with 39.29 % and 33.80 % respectively. This practice is relatively less demanding in labour compared to composting. This also obeys to a strategy from these two poorly endowed farm-types: with less access to chemical fertilizer and low labour endowment, these farmers are resorting to animal dung use to provide their land with nutrients. As for stone bunds, apart from farm-type III (labourless) which present the lowest proportion of farms using the technology (25.35 %), all the others farm-types have at least 32 % of their members using stone bunds to preserve and improve soil fertility. Farm-type IV has the highest proportion (51.72 %) of farmers using this technology.

Table 3: Use of conservation agriculture practices by farm-types (%)

Farm-type	Recycling crop residues	Using manure	Using stone bunds
I	26.67	25.71	37.14
II	23.53	26.47	32.35
III	19.72	33.80	25.35
IV	24.14	17.24	51.72
V	21.43	39.29	42.86
Total	23.60	28.06	34.93

Conclusion

On the basis of livelihood assets endowment, the study found in the study area five typical farms: two better-off farm-types, one is cotton and livestock based, and the second is non-farm preference; a medium farm-type labour-rich and marketable food crop oriented; a poor, insecure-land tenure, livestock based farm-type; and finally a pro-poor, labourless-and landless farm-type. Soil fertility management characterization of these five farm-types showed there is a correlation between the livelihood profile and fertility management options in use by farms. Wealth, livelihood strategy, land access, labour availability and existing policies are factors determining nutrient management strategies.

- Better-off farm-types intensify fertilizer use with livelihood orientation and supporting policy. Better-off cotton-and livestock based farm-type (farm-type I) has best performance in chemical fertilizer use and recycling crop residues. The so called conventional cotton producers are maximizing on chemical fertilizer use while biological cotton producers focus on compost use. Better-off non-farm preference farm-type (farm-type II) is less incline to investing in chemical fertilizer use and seems to be turned on use of manure and stone bunds.

- Medium income, labour-rich, marketable food crop oriented and educated farms (Farm-type IV) that we consider as most diversified farms are also diversifying their sources of nutrient input. They have relatively good fertilizer use intensity and the highest proportion of farms recycling crop residue after farm-type I. 51% of them use stone bunds.

- Least endowed farm-types (III and V) intensify fertilizer use with land constraint. The Pro-poor farm-type, landless and labourless (farm-type III) focus on intensification of mineral fertilizer while Poor, insecure-land tenure, livestock based farm-type (farm-type V) intensifies less and has a bigger proportion of farmers using manure.

References

Belcher, K. W., Boehm, M. M. & Fulton, M. E. (2004). Agroecosystem sustainability: a system simulation model approach. Agricultural Systems 79: 225–241.

Below, T., Artner, A., Siebert, R. & Sieber, S. (2010). Micro-level Practices to Adapt to Climate Change for African Small-scale Farmers A Review of Selected Literature IFPRI: 21.

De Jager, A., Nandwa, S. M. & Okoth, P. F. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON) I. Concepts and methodologies. Agriculture, Ecosystems and Environment 71: 37- 48.

DFID (1999). Sustainable livelihoods guidance sheets. http://www.efls.ca/webresources/DFID_Sustainable_livelihoods_guidance_sheet.pdf

Gleisberg-Gerber, K. (2012). Livelihoods and land management in the Ioba Province in south-western Burkina Faso.

Le, Q. B., Seidl, R. & Scholz, R. W. (2012). Feedback loops and types of adaptation in the modelling of land-use decisions in an agent-based simulation. Environmental Modelling & Software 27-28: 83-96.

MAHRH & GTZ (2004). Mission d'appui à l'identification des interventions du Programme de Developement de l'Agriculture de la coopération germano-burkinabè dans la région administrative du Sud-Ouest. Ouagadougougou,

Matthews, R. (2006). The People and Landscape Model (PALM): Towards full integration of human decision-making and biophysical simulation models. Ecological Modelling 194: 329-343.

McCown, R. L., Hammer, G. L., Hargreaves, J. N. G., Holzworth, D. & Huth, N. I. (1995). APSIM-An agricultural production system simulation model for operational research. Mathematics and Computers in Simulation 39: 225-231.

McCown, R. L., Hammer, G. L., Hargreaves, J. N. G., Holzworth, D. P. & Freebairn, D. M. (1996). APSIM: a novel software system for model development, model testing, and simulation in agricultural systems research. Agricultural Systems 50: 255-271.

Reardon, T. & Vosti, S. A. (1995). Links Between Rural Poverty and the Environment in Developing Countries: Asset Categories and Investment Poverty World Development 23: 1495-1506.

Sconnes, I. (1998). Sustainable rural livelihoods. A framework for analysis. IDS Working Paper 72.

Sherbinin, A. d., VanWey, L. K., McSweeney, K., Aggarwal, R., Barbieri, A., Henry, S., Hunter, L. M., Twine, W. & Walker, R. (2008). Rural household demographics, livelihoods and the environment. Global Environmental Change 18: 38-53.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Rowe, E. C., Giller, K. E. & Bacha, D. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya I. Heterogeneity at region and farm scale. Agriculture, Ecosystems and Environment 110: 149-165.

Van den Bosch, H., Jager, A. D. & Vlaming, J. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development. Agriculture, Ecosystems and Environment 71: 49-62.