Agricultural Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Simulating agricultural land-use adaptation decisions to climate change: An empirical agent-based modelling in northern Ghana

Mahamadou L. Amadou[a,e,1,*], Grace B. Villamor[b,c], Nicholas Kyei-Baffour[d]

[a] AGRHYMET Regional Centre, Niamey, Niger
[b] Centre for Development Research (ZEF) University of Bonn, Germany
[c] Center for Resilient Communities, University of Idaho, USA
[d] Agriculture Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[e] Catholic Relief Services (CRS), Niamey, Niger

ARTICLE INFO

Keywords:
Agent-based model
Climate change
Decision making model
Heterogeneous farm households
SKY-LUDAS
Subsistence farming

ABSTRACT

In West Africa, the majority of regional climate projections for the region predict that the study area will become warmer and that precipitation patterns will be more erratic. The aim of this article is to examine local agricultural adaptation to climate change and variability in a semi-arid area of the Upper East Region of Ghana. This is performed by integrating the two-step decision making sub-models, Perception-of-Climate-Change and Adaptation-Choice-Strategies, to the Land Use Dynamic Simulator (LUDAS). The simulation results suggest that the land-use choices in the study area reflect a tendency towards increasing subsistence farming in an area where there has been a gradual trend away from traditional land uses such as cereal production to the cultivation of groundnut, rice, maize and soybean. Groundnut monoculture production has emerged locally as coping measure for dealing with increased climatic variability. In terms of livelihood strategy, there is an increasing contribution of rice and groundnut to household gross incomes. The predicted pattern of changes in gross household income under a scenario in which climate change is perceived by local farmers explicitly revealed the contribution of adaptation options to household livelihood strategy.

1. Introduction

Analyses of climate change and agricultural land use require a complex systems approach in which both human and environmental dynamics are studied over range of spatial and temporal scales. This approach can provide the information needed to understand interlinkages among environmental and social problems, but it is only possible by integrating multidisciplinary research methods with dedicated disciplinary research on individual processes and mechanisms (Carpenter et al., 2009; Huber et al., 2013). One of the operationalised tools for this approach is the agent-based model (ABM).

In the recent years there has been broader application of this tool, especially with respect to land-use/cover change (LUCC) where ABM have proven to be suitable tools for representing complex spatial interactions under heterogeneous conditions and for modelling decentralized, autonomous decision making (Parker et al., 2003; Bousquet and Le Page, 2004; Schreinemachers and Berger, 2011; Schouten, 2013; Latynskiy, 2014; Villamor et al., 2014). A growing number of ABM have been built for evaluating individual farm decision making in terms of agricultural land-use systems (Parker et al., 2003), especially in the simulation of adaptation to climate change (Schreinemachers and Berger, 2011, Troost et al., 2012, Badmos et al., 2015; Christian Troost and Berger, 2015, Christian Troost, 2014). In west African context, number of research implementing ABM were developed including; SimSahel model for investigating impacts of development interventions on the Nigerien population villages (Saqalli et al., 2013a), and detecting social organisation change in Western villages of Niger (Saqalli et al., 2010; Saqalli et al., 2013b); and CaTMAS model for analyzing carbon dynamics of farming systems and sustainability of farming system in Burkina Faso (Belem et al., 2011). In the Upper East Region of Ghana LUDAS model was implemented for simulating the impact of policy interventions on land-use/cover patterns and soil loss from agro-ecosystems (Schindler, 2009; Badmos et al., 2014, 2015). Results of previous studies suggest that in order to improve estimates of climate change impacts on agricultural land uses and contribute more efficiently to adaptation research (Balbi and Giupponi, 2009; Matthews et al., 2007; Wijk et al., 2012), there is a need to better understand how farmers perceive local climate conditions and respond over both the

* Corresponding author. AGRHYMET Regional Centre, Niamey, Niger.
E-mail addresses: a.laouali@agrhymet.ne, laouali.amadou@crs.org, laouali@gmail.com (M.L. Amadou), gracev@uni-bonn.de, gvillamor@uidaho.edu (G.B. Villamor).
[1] Present address: AGRHYMET Regional Centre, Niamey, Niger

https://doi.org/10.1016/j.agsy.2017.10.015
Received 17 April 2017; Received in revised form 16 October 2017; Accepted 23 October 2017
0308-521X/

short and long-term to various climate change scenarios, including the magnitude and frequency of extreme conditions (Smit et al., 1996). The use of ABM for the operationalisation of adaptive decision making about agricultural land use based on farmer perceptions of climate change and variability could help avoid misdirected adaptation efforts by isolating planned adaptation from a large number of traditional autonomous adaptation practices (Pentjuss et al., 2011; Badmos et al., 2014; Troost, 2014; Troost and Berger, 2015). The environmental specificity of agricultural adaptation options implies that most climate change adaptation options are unlikely to be undertaken independently of related risk-management initiatives. Risk management research findings, however, recognise that agricultural decisions involve both risk assessment and the determination of specific actions that can be taken to reduce, transfer or mitigate risk (Smit and Skinner, 2002).

Perceptions and decision making for predicting future land-use changes under climate change scenarios are either viewed as lacking in most land-use modelling exercises (Rounsevell et al., 2012; Verburg et al., 2016), or as rarely being directly linked to actual practices and behaviours (Meyfroidt, 2013). For this reason, we focused this research on: (1) the exploration of possible changes in dominant agricultural land uses, and (2) the implications of farmer decisions about agricultural land-use adaptation to climate change and variability in the specific context of a semi-arid region in Ghana. We adapted the framework of Land Use Dynamic Simulator (LUDAS) (Le et al., 2008). The ODD protocol (Grimm et al., 2006, 2010) of LUDAS model is explicitly described in Le et al. (2010) and Villamor et al. (2014), whereas the ODD + D protocol is described in (Villamor and Van Noordwijk, 2016). The LUDAS approach was adapted and implemented as GH-LUDAS in the Upper East Region of Ghana (Schindler, 2009; Badmos et al., 2015) and as LB-LUDAS for capturing the gendered decision making in Sumatra, Indonesia (Villamor and Van Noordwijk, 2016). In this study, we integrated into the LUDAS framework the two-step decision-making sub-model as a modification or add-on module and described using the Overview, Design, Detail plus Decision-making (ODD + D) protocol (Müller et al., 2013). We specifically focused on integrating climate change perceptions into decision-making routines. This included a research question regarding how farmers perceive risks associated with climate change (Amadou et al., 2015) and the key question about what type of stimuli agricultural land-use changes are adapting to.

2. Methodology

2.1. Study area description

The study area is located in the Atankwidi catchment in the Upper East Region (UER) of Ghana between the districts of Navrongo and Bolgatanga (Fig. 1). The study area coordinates are between 10°50′41″—11°00′35″ N latitude, and 1°03′47″—0°53′02″ W longitude. Within the catchment, the study area focused on 192 km^2 populated by four villages: Sumbrungu, Sirigu, Kandiga and Yuwa (Amadou et al., 2015). Agriculture is the main economic activity in the area. Small-scale farm households typically engage in activities such as the production of artisanal goods, trading, wood cutting and livestock production, which constitute the main sources of cash income. Most of the available land area is dedicated to small-scale agriculture during the rainy season (May–October). The area is covered by scattered household compounds that are usually surrounded by mixed crop production systems of cereals (*Sorghum bicolor* and *Pennisetum spp*), groundnut (*Arachis hypogaea*) and rice (*Oryza sativa*). There are a limited number of uncultivated patches scattered among the crop production areas that serve as grazing areas for local livestock. From the 2012 land-cover map of the area (Gerald et al., 2014), eight land-use types were classified (Fig. 2). The proportions of these land-types are reported in Table 1.

The study area is located in one of the poorest regions of Ghana where research on policy intervention impacts on local socio-economic and agro-ecological conditions is of considerable importance, especially for supporting sustainable local livelihoods.

The study area is characterised by clear seasonal changes between the dry and rainy seasons (Laube, 2005). Rainfall is marginal from November to April, with a slightly increased likelihood of rain in April, followed by almost all annual precipitation occurring between May and October. The mean precipitation from 1970 to 2010 of the closest weather station to the study area (Navrongo) is 989.57 mm. Temperatures are considerably higher than in the rest of the country, with mean monthly temperatures ranging between 18 °C and 38 °C (Martin, 2006).

The uni-modal annual precipitation pattern of the study area limits agricultural capacity and thereby the labour potential locally, as most residents are only fully engaged in agricultural labour during the brief wet season and remain without work for the rest of the year (Yaro 2000, cited in Schindler, 2009). For this reason, seasonal migration occurs from October to May (Saqalli et al., 2013a) when young adults go down to urban areas (Tamale, Kumasi, Accra, etc.) to find jobs (Laube et al., 2012).

2.2. Data collection and analysis

A total of 186 households distributed among the four villages in the study area were randomly selected and surveyed. The survey sample composition was 15% female-headed households and 85% male-headed households. Most household heads ranged ages 30 to 76. Household socio-economic data were collected using a semi-structured questionnaire during a survey conducted between January and April 2013. Three main components of agricultural land-use systems in the study area were explored through the questionnaire: (1) farming systems, (2) farmer perceptions of climate change and variability, and (3) climate change adaptation strategies. We applied Principal Component and K-means cluster analyses to derive three household agent groups. The descriptive statistics of these agent groups and corresponding livelihood indicators (variables) are summarised in Table 2. Specific agent behaviour with respect to the land use of each agent group was determined from a multinomial logistic regression (m-logit) analysis. The m-logit analysis was used to assess the choice of adaptation options and perceptions about climate change and variability were assessed based on the binary logistic regression, which in turn served as the basis for the two-step decision making sub-models (see Section 2.3.3).

2.3. Sirigu-Sumbrungu-Kandiga-Yuwa (SKY)-LUDAS: model description

The SKY-LUDAS model was developed to explicitly integrate two-step decision making used to assess the implications of climate risk perception with respect to adaptation decisions (Amadou, 2015). The land-use types (e.g., mixed cereal, groundnut, or rice production systems and pastures) generated by the land-use/cover classification of the study area (Gerald et al., 2014) and key livelihood indicators (e.g., gross income, income contributions of each land-use type, and household size of each household agent group) were considered during the model simulation. Each time step was equal to one production year. Five simulation runs were performed to compute the mean and the standard error values of each indicator.

2.3.1. Overview

2.3.1.1. Purpose. The SKY-LUDAS model is based on the previous versions of LUDAS, which were designed to: (1) support land-use decisions in the forest margins of Vietnam in consideration of different land-use policy interventions (Le et al., 2010); (2) explore the impact of policy interventions on future land-use/cover patterns and income indicators in the Upper East Region of Ghana (Schindler, 2009); and (3) explore the potential trade-offs and synergies of policy interventions on the goods and services along temporal and spatial dimensions in Indonesia (Villamor et al., 2014). SKY-LUDAS was developed for this study to explore the complex dynamics of agro-ecological systems based on how household farming systems perform