Reg Environ Change
DOI 10.1007/s10113-015-0838-6

ORIGINAL ARTICLE

Linking agricultural adaptation strategies, food security and vulnerability: evidence from West Africa

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Received: 20 November 2014 / Accepted: 20 June 2015

Abstract Adaptation strategies to reduce smallholder farmers' vulnerability to climate variability and seasonality are needed given the frequency of extreme weather events predicted to increase during the next decades in sub-Saharan Africa, particularly in West Africa. We explored the linkages between selected agricultural adaptation strategies (crop diversity, soil and water conservation, trees on farm, small ruminants, improved crop varieties, fertilizers), food security, farm household characteristics and farm productivity in three contrasting agro-ecological sites in West Africa (Burkina Faso, Ghana and Senegal). Differences in land area per capita and land productivity largely explained the variation in food security across sites. Based on land size and market orientation, four household types were distinguished (subsistence, diversified, extensive, intensified), with contrasting levels of food security and agricultural adaptation strategies. Income increased steadily with land size, and both income and land productivity increased with degree of market orientation. The adoption of agricultural adaptation strategies was widespread, although the intensity of practice varied across household types. Adaptation strategies improve the food security status of some households, but not all. Some strategies had a significant positive impact on land productivity, while others reduced vulnerability resulting in a more stable cash flow throughout the year. Our results show that for different household types, different adaptation strategies may be

Editor: Wolfgang Cramer.

Electronic supplementary material The online version of this article (doi:10.1007/s10113-015-0838-6) contains supplementary material, which is available to authorized users.

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'climate-smart'. The typology developed in this study gives a good entry point to analyse which practices should be targeted to which type of smallholder farmers, and quantifies the effect of adaptation options on household food security. Subsequently, it will be crucial to empower farmers to access, test and modify these adaptation options, if they were to achieve higher levels of food security.

Keywords Adaptation strategies · Climate variability and change · Income · Land productivity · Market orientation · Typology

Introduction

The serious challenge posed by climate change on food security in rural sub-Saharan Africa is well documented and concerns on its impact have been raised by a plethora of authors (e.g. Brown and Funk 2008; Battisti and Naylor 2009; Conway 2011; Beddington et al. 2012; Thornton et al. 2012; Thornton and Herrero 2014). Although the scientific community started looking for appropriate responses to climate change years ago (Downing et al. 1997), questions remain with respect to how, where and for whom different adaptation strategies work (Adger et al. 2003; Challinor et al. 2007; Cooper et al. 2008).

West Africa is a particularly vulnerable region due in general to the low adaptive capacity of rural households and the exposure to natural and anthropogenic threats (Sissoko et al. 2011). Changes in behaviour and agricultural practices in order to adapt to a changing climate are seen as critical to improve livelihoods and food security for millions of rural households in the region (van de Giesen et al. 2010; Vermeulen et al. 2012). Most of the agricultural adaptation strategies suggested in the literature are not new, but have been evolving from traditional practices and/or have been promoted decades ago in response to major drought events (Dugué et al. 1993; Mortimore and Adams 2001). Soil and water conservation (SWC) practices allow increasing soil water content and maintaining humidity during dry spells through an improved soil structure (Rockström et al. 2002). Trees can provide shade, biomass and an additional source of income (i.e. fuel wood, charcoal) during the dry season (Akinnifesi et al. 2008), as well as numerous ecological functions (Lasco et al. 2014). Vegetable production, or market gardening, is a dry season strategy, to take advantage of the available labour force and make use of small reservoirs and wells to produce vegetables when prices are higher (Barbier et al. 2009). Small ruminants provide insurance and a substantial source of income, and help spread income risk (McDermott et al. 2010). Crop diversity is a strategy for risk avoidance due to sharp fluctuations in crop yield or prices (Van Noordwijk and Van Andel 1988; Ellis 2000). The application of mineral fertilizer increases yields, allowing farmers to build up food/financial reserves. Improved varieties (drought tolerant and/or short cycle) allow for increased productivity even during dry seasons (Lobell et al. 2008).

Despite the upsurge in the promotion of such adaptation strategies in recent years, there is surprisingly a lack of thorough analyses of their impacts on food security. We conducted a comprehensive survey in three contrasting sites to capture detailed information at household level on farm resources, farm management strategies, farm productivity, food consumption and household economics. The objectives were (1) to define food-secure and food-insecure household profiles, (2) to explore the linkages between household characteristics and adoption of seven agricultural adaptation strategies and (3) to assess the impact of these strategies on food security and farm productivity. Our hypothesis was that adoption of agricultural adaptation strategies makes a significant contribution to household-level food security for all farm households, although we expect differences between farm households on the type of strategies adopted.

Methods

Site characteristics

The study was conducted in 2012 at sites in Burkina Faso (Yatenga), Ghana (Lawra-Jirapa, referred to in the text as Lawra) and Senegal (Kaffrine). These sites were identified in

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2010 as benchmark sites of the CGIAR research programme on Climate Change, Agriculture and Food Security (www.ccafs.cgiar.org). The sites, square blocks of 30 × 30 km in Burkina Faso and Senegal, and of 10 × 10 km in Ghana, were chosen in a participatory approach with different stakeholders (National Agricultural Research Centers, NGOs, government agents and farmers' organizations) using criteria such as poverty levels, vulnerability to climate change, key biophysical, climatic and agro-ecological gradients, agricultural production systems and partnerships (Förch et al. 2011). A brief summary of climate, farming systems and major resource constraints at each of the sites is presented in the Supplementary Materials (Table SM1), whereas detailed descriptions are given by Sijmons et al. (2013a, b, c). These sites are also hot spots of climate change and food insecurity as identified by Ericksen et al. (2011).

Sampling strategy and survey implementation

For this study, we surveyed 600 households (200 per site) using a stratified sampling strategy and 'IMPACTlite' survey methodology described in detail in Rufino et al. (2012). The data are available online at https://thedata.harvard.edu/dvn/dv/CCAFSbaseline/ (Silvestri et al. 2014). The first layer of the sampling strategy consisted in identifying key agricultural production systems within each of the CCAFS sites. High-resolution satellite images, transect drives and interviews with local experts and key informants were used to identify these production systems. Within each of the identified production systems, representative villages were randomly selected up to a total of 20 villages per site. In each village, ten households were randomly selected from a list of all households. All households were interviewed using a questionnaire that included information on: detailed household composition and structure, crop and livestock production and management, household economy (assets, incomes and expenses) and food consumption.

Conceptual framework: indicators measured

Two sets of indicators were used to explain the differences in food security: the general characteristics of the households and their productivity on one side, and the adoption and the intensity of practice of agricultural adaptation strategies on the other side. The full list, as well as the values taken by these indicators for each site, is given in the Supplementary Materials (Table SM2).

Food security and food self-sufficiency

The World Food Summit of 1996 defined food security as existing 'when all people at all times have access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (FAO 1996). In this study, we do not cover important aspects of nutrition, health, water and sanitation, but rather focus on a key pillar of food security, i.e. food availability, where the goal is to obtain sufficient quantities of food of appropriate quality available at household level throughout the year. Food security and food self-sufficiency ratios were calculated following Rufino et al. (2013). Food security ratio is the ratio of the energy consumed by a household, from on-farm as well as purchased products, divided by the energy requirements of the household. Food self-sufficiency ratio is the ratio of the energy consumed by a household from on-farm products, divided by the energy requirements. Households were considered food secure if the ratio is larger than 1.

$$\mathrm{SSR} = \frac{\sum_{i=1}^{n} (\mathrm{QF}_i * E_i)}{\sum_{k=1}^{h} \mathrm{ER}_k}$$

$$\mathrm{FSR} = \frac{\sum_{i=1}^{n} (\mathrm{QF}_i * E_i) + \sum_{j=1}^{m} \left(\mathrm{QP}_j * E_j\right)}{\sum_{k=1}^{h} \mathrm{ER}_k}$$

where SSR is the food self-sufficiency ratio, FSR is the food security ratio, QF_i is the quantity of consumed farm product i (kg or l), QP_j is the quantity of purchased product j (kg or l), E_i and E_j is the energy content of product i or j (MJ kg^{-1} or l), ER_k is the energy requirement of household member k, and h is the total number of members in the household considered.

The ratios were calculated on an annual basis. Quantities consumed per year were calculated from the quantities consumed per month during the good and bad periods and multiplied by the length in months of the respective periods. Daily energy requirements for each gender and age group, using World Health Organization standards (FAO 2004), were summed and multiplied by 365.

Assets

Assets are a key indicator of the degree of poverty (Carter and Barrett 2006); households with more assets are more likely to adopt new agricultural practices (Wood et al. 2014). Asset indices were calculated as the sum of the number of assets, weighted by type and age of the asset, following Njuki et al. (2011). Domestic assets (radio, cooker, cell phones, etc.), transport-related assets (bicycle, motorbike, etc.) and agricultural productive assets (hoes, ploughs, pumps, etc.) were distinguished. Productive assets enhance a household's capacity to produce food. Transport assets aid access to markets and make it easier to attend meetings and events and thus access information and social networks, as do domestic assets such as cell phones (Kassie et al. 2014).

Income

Total net income was calculated as the sum of annual net farm income (gross income from sales of livestock and crops minus production costs) and annual net off-farm income (off-farm earnings minus related expenses). Income from crop production includes incomes from sale of crop products, crop residues and plot rental. Off-farm income from sources such as artisanal work, commerce, gold mining, wage employment and remittances contributes to buffer production risks associated with climate variability and to stabilize cash flows and food consumption (Brown et al. 1994). Gross income was divided into its various components to calculate the per cent contribution of the various activities to total income. The value of agricultural products kept for home consumption purposes was not included in this analysis, so what we are considering here is in effect cash income earnings of households.

Land productivity and labour force

Smallholder farm households are typically characterized by a strong reliance on labour for production and income generation, and this variable is therefore an important driver of household-level food security (Brown et al. 1994). Available labour was calculated as the number of members between 15 and 60 years old (i.e. the active members) divided by the number of other household members (i.e. the passive members, or dependents). Land productivity was calculated as the sum of crop and livestock products, in terms of energy, divided by the total farm area.

Market orientation

Market orientation was calculated as the ratio of the monetary value of on-farm products sold to the value of everything produced (i.e. including for home consumption). The higher the ratio, the more market-oriented the household.

$$\mathrm{MO} = \frac{\sum_{i=1}^{n}\left(\mathrm{QCs}_i * \mathrm{CE}_i\right) + \sum_{j=1}^{m}\left(\mathrm{QLs}_j * \mathrm{CE}_j\right)}{\sum_{i=1}^{k}\left(\mathrm{QCp}_i * \mathrm{CE}_i\right) + \sum_{j=1}^{l}\left(\mathrm{QLp}_j * \mathrm{CE}_j\right)}$$

where MO is market orientation, QCs and QLs are the quantity of crop and livestock product i and j sold on the market (kg or l), QCp and QLp are the quantity of crop and livestock product i and j produced on-farm (kg or l), and CE_i and CE_j are the cash equivalent of product i and j (USD kg^{-1} or l).

Increased market orientation can have two opposing effects on food security: through increased diversification, it improves both the level of food consumption in normal times and the ability to cope during bad times, but if it is accompanied by a big fall in subsistence production, it can have a deleterious effect on food security (IFAD 2014). In addition, if markets are working well, the circulation of cash increases in rural areas and gives households broader opportunities to construct pathways out of poverty (Ellis and Freeman 2004).

Agricultural adaptation strategies

The agricultural adaptation strategies chosen were the practices most frequently cited by respondents, as well as promising practices identified in consultation with local research and development partners. An estimation of the intensity of practice was calculated for each agricultural adaptation strategy considered. Crop diversity was calculated as the number of different crops grown per household. The proportion of the cropping area with the presence of SWC, trees (incl. fruit trees) or vegetables was used as proxy for the intensity of these practices at farm level. SWC practices included planting pits ('zaï'), contour bunds, half-moons, application of manure, mulch, tied ridges and life barriers (Douxchamps et al. 2012). Vegetable production included all vegetable crops as well as fruits commonly found in market gardens (e.g. melon). The intensity of mineral fertilizers application was calculated as the total amount of fertilizer applied over the total cropping area. The use of improved varieties by a household was characterized as the ratio of crops with improved varieties over the total number of crops. The intensity of small ruminants practice was assessed by the number of goats and sheep raised by the household.

Adaptation options that are implemented at community level, for example reforestation, use of improved forages in grazing area, and development and use of communal water basins/ponds were not considered in this household-level study because communal resources were not included. Neither did we include non-biophysical adaptation practices such as farmer involvement of local self-help or savings groups, farmer involvement in insurance schemes and farmer investments in creating off-farm income opportunities (e.g. through schooling of their children).

Data analysis

The relationships between household characteristics and adaptation strategies were explored using various univariate and multivariate techniques. Generalized linear models were fitted for food security and farm characteristics for all sites. The best model structure was selected by model averaging and the Akaike information criterion, using the package AICcmodavg in R (R development Core Team 2007). Then, based on the key explanatory variables for food security and adoption of adaptation strategies, a household typology was developed (details below in 'Typology of households practicing adaptation strategies' section) and tested by performing a canonical analysis on principal coordinates, using the CAP programme (Anderson 2004). Linear multiple regressions were performed to assess the contribution of agricultural adaptation strategies to productivity for each type of household. The significance level chosen was $P = 0.05$. Kruskal–Wallis tests were used to assess significant differences ($P < 0.05$) between types of households.

Results

Household food security

Food security status and contributions to income

The proportion of food-secure households per site was 48, 18 and 55 % in Kaffrine (Senegal), Lawra (Ghana) and Yatenga (Burkina Faso), respectively. The characteristics, agricultural adaptation strategies and the average contributions of various activities to gross (cash) income for food-secure and food-insecure households in the three sites are given in the Supplementary Materials (Figure SM1 and Table SM2). Sales of staple crops (mainly millet, sorghum, maize, cowpea and groundnut) and off-farm earnings made up the majority of households' gross income in all sites. Despite being the main contributor to food security, cereals were sold by the food-insecure households, although in a lower proportion than by the food secure in Kaffrine and Lawra. At all sites, the food-secure households obtained more income from livestock than the insecure ones, with livestock making up to 25 % of income in Yatenga.

Food security and agricultural adaptation strategies

Factors explaining variation in food security

The best model structure to explain food security based on productivity and adaptation strategies across all sites is presented in Table 1. The key factor influencing food security was total land area per capita. The number of adaptation strategies practised and off-farm income, which is also strongly correlated with market orientation, were the two other explanatory variables retained after model simplification. Crop diversity and market orientation did not explain variation in food security.

Typology of households practicing adaptation strategies

In order to group households that have similar characteristics and pursue certain adaptation options, we developed a typology based on total land area used per capita (a key explanatory variable for both food security and adoption of adaptation strategies) and market orientation (a key explanatory variable for adoption of adaptation strategies; Fig. 1). This approach is similar to typologies developed in other studies, also based on land area and off-farm income (Waithaka et al. 2006; Tittonell et al. 2010), and contrasts with typologies based only on resource endowment (Kamanga et al. 2010; Giller et al. 2011). The thresholds along these two axes were determined as the lowest value of the axis for which the performance of resulting groups was significantly different. Food self-sufficiency was used as performance indicator for the total area per capita axis, and total gross income from farm products per ha was used for the market orientation axis. The thresholds vary for each site, as they depend on the sample distribution as well as the regression between the axes and the performance indicators chosen to define the thresholds (results not shown). This a priori typology was subsequently tested using canonical plots (Supplementary Materials, Figure SM2) and adjusted to minimize misclassification errors.

This typology shows significant differences between the adoption of adaptation strategies and household characteristics that were not evident using multivariate analyses (results not shown). The relative importance of farm household characteristics, agricultural adaptation strategies adoption (presence or absence of the strategies) and agricultural adaptation strategies intensity (as defined in 'Agricultural adaptation strategies' section) for each household type is presented in the Supplementary

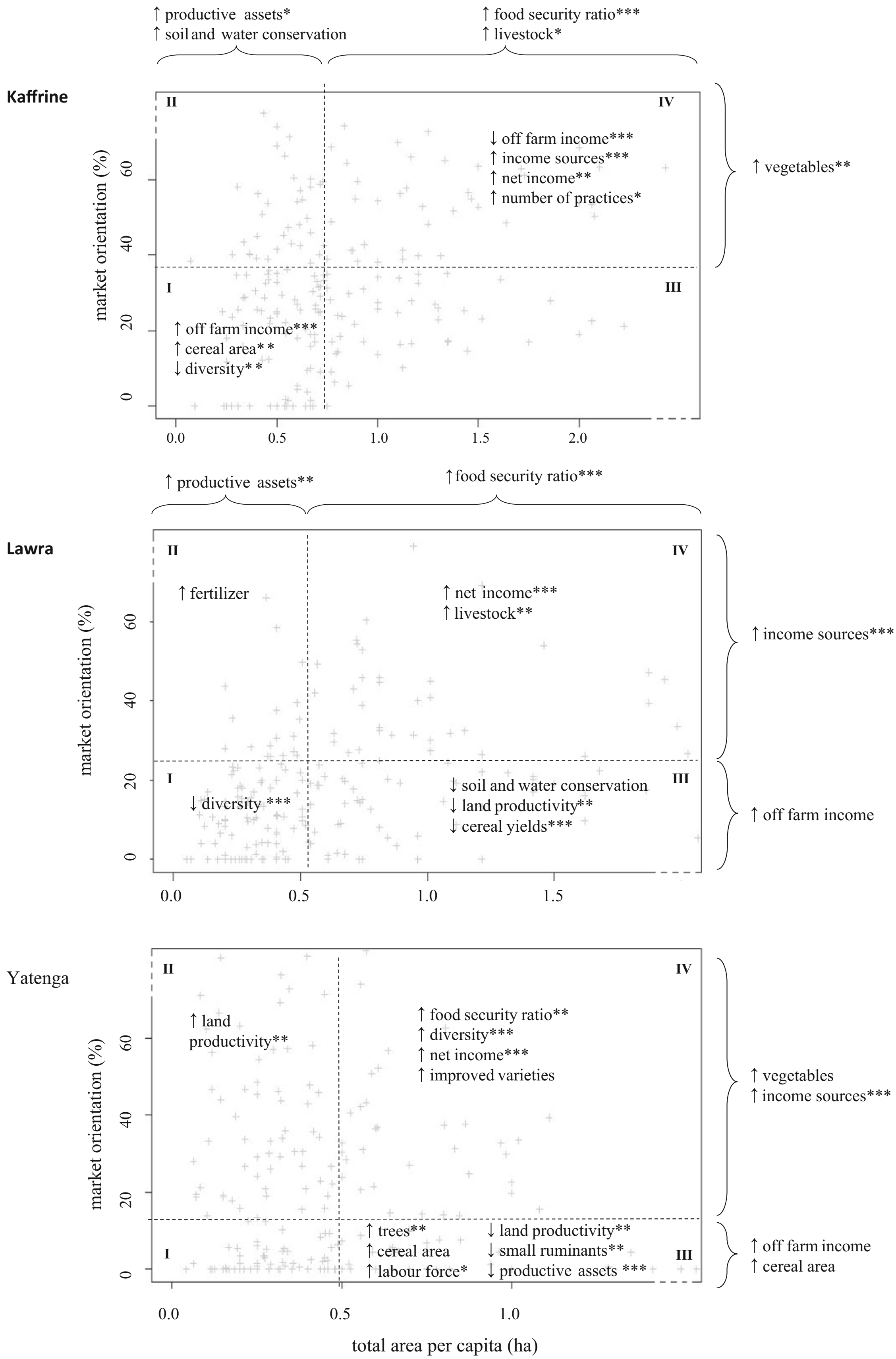
Table 1 Stepwise multiple regression of food security and farm characteristics, productivity and agricultural adaptation strategies

	Estimate	Std. error	*t* value	*P* value
Intercept	1.752	0.352	4.973	0.000***
Labour force				
Domestic and transport asset index				
Total area per capita	0.361	0.174	2.074	0.038*
TLU per capita				
Market orientation				
Off-farm income	0.003	0.002	1.206	0.228
Nb of practices	−0.178	0.066	−2.679	0.007**

Null deviance: 2887 on 592 degree of freedom

Residual deviance: 2825 on 589 degree of freedom

*** highly significant; ** very significant; * significant


↑ productive assets*
↑ soil and water conservation
↑ food security ratio***
↑ livestock*
Kaffrine
II
IV
↓ off farm income***
↑ income sources***
↑ net income**
↑ number of practices*
↑ vegetables**
I
III
↑ off farm income***
↑ cereal area**
↓ diversity**
market orientation (%)
0
20
40
60
0.0
0.5
1.0
1.5
2.0
↑ productive assets**
↑ food security ratio***
Lawra
II
IV
↑ fertilizer
↑ net income***
↑ livestock**
↑ income sources***
I
III
↓ diversity ***
↓ soil and water conservation
↓ land productivity**
↓ cereal yields***
↑ off farm income
market orientation (%)
0
20
40
60
0.0
0.5
1.0
1.5
Yatenga
II
IV
↑ land productivity**
↑ food security ratio**
↑ diversity***
↑ net income***
↑ improved varieties
↑ vegetables
↑ income sources***
I
III
↑ trees**
↑ cereal area
↑ labour force*
↓ land productivity**
↓ small ruminants**
↓ productive assets ***
↑ off farm income
↑ cereal area
market orientation (%)
0
20
40
60
0.0
0.5
1.0
total area per capita (ha)

◀**Fig. 1** Household a *priori* typology based on total area per capita and market orientation, with the respective household characteristics and agricultural adaptation strategies for the three sites. *Arrows* show if the indicator for a certain type of household is higher or lower than for the other types. *Stars* indicate the level of significance of this difference as follows: ***$P < 0.001$; **$P < 0.01$, *$P < 0.05$

Materials (Figure SM3) and shows that household types differ in the intensity of their practice of adaptation strategies, rather than in the adoption itself. Four distinct household types can be distinguished in the analyses represented in Fig. 1:

Type I: Subsistence farming. Households cropping a small land area per capita with low market orientation, focusing on staple foods, but not self-sufficient. Few are food secure (30 %). They rely on off-farm income and relatively more productive assets per ha than the other types. Type I households obtain a higher proportion of income from non-ruminants (mainly poultry). This household type adopted more practices and engages in SWC more intensively than the other types of households

Type II: Diversified farming. Crop diversification and intensification on small areas, with relatively high market orientation and high land productivity compared to Type I, more income sources, a higher income from cattle and slightly more food secure than Type I (40 %). This type of household cultivates larger areas with vegetables (Kaffrine and Yatenga), uses more fertilizer (Lawra) and practises more SWC (Kaffrine) than the other types

Type III: Extensive farming. Low market orientation, focusing on staple food crops, with more labour use and greater self-sufficiency, but producing lower cereal yields and with lower land productivity than the other types and relying on off-farm income as a safety net. Significantly more food secure (55 %) than Types I and II, this group also has more livestock assets

Type IV: Intensified farming. Diversified crops and livestock on relatively larger areas, with high market orientation. This household type has the highest proportion of income coming from pulses (mainly groundnut). Type IV households are mostly self-sufficient, relying on various on-farm income sources, and are significantly more food secure (59 %) than the others. This type of household practises agricultural adaptation strategies more intensively than the other types, with more crop diversity and vegetable production (Kaffrine and Yatenga), small ruminants (Kaffrine), and improved varieties (Yatenga)

The least food-secure households (Type I) are also those who practise agricultural adaptation strategies less intensively. The extensive farming type (Type III) compensates for lower land productivity and low levels of agricultural adaptation strategies with a larger area per capita for staple food production, plus they have a higher off-farm income that is likely providing them food security. There are many food-insecure households found in the diversified household category that are also pursuing agricultural intensification strategies. However, the difference between food-secure and food-insecure households in this group is not

Table 2 Linear multiple regression of land productivity (expressed in terms of energy per ha) and agricultural adaptation strategies for each type of household

	Type I		Type II		Type III		Type IV	
	Coefficient	*P* value	Coefficient	*P* value	Coefficient	*P* value	Coefficient	*P* value
Intercept	3.341	0.000***	3.698	0.000***	3.721	0.000***	3.155	0.000***
Trees	−0.001	0.915	0.001	0.699	−0.003	0.012*	0.001	0.731
Soil and water conservation	0.086	0.039*	−0.049	0.280	−0.088	0.091	−0.06	0.257
Vegetables	−0.098	0.112	−0.086	0.237	0.052	0.457	−0.276	0.000***
Crop diversity	0.315	0.113	−0.067	0.763	0.219	0.365	0.812	0.000***
Small ruminants	0.131	0.036*	0.301	0.000***	0.071	0.328	0.151	0.042*
Mineral fertilizers	0.072	0.055	0.087	0.053	0.037	0.416	0.058	0.184
Improved varieties	0.067	0.164	−0.065	0.291	0.042	0.456	0.085	0.155
R^2	0.10		0.14		0.14		0.29	
P value	0.000		0.008		0.046		0.000	

*** highly significant; * significant

related to these strategies; more food-secure household simply have higher land productivity.

Farm size and market orientation and the performance indicators (land productivity and income) show a positive and linear relationship in all cases, except for the relationship between land productivity and total area per capita (Supplementary Materials, Figure SM4). In other words, income increases steadily with land size, and both income and land productivity increase as households become more market oriented.

Land productivity and adaptation strategies

Adoption of adaptation strategies only partially explains the variance in land productivity, with an explained variance increasing from 10 to 29 % from Types I to IV (Table 2). For households with low market orientation (Types I and III, subsistence and extensive farming), these agricultural practices play a minor determining role in land productivity (Table 2). For households with higher market orientation (Types II and IV, diversified and intensified farming), a few practices contribute significantly to productivity, especially small ruminants for households with small crop area per capita (Type II), while diversification and vegetable production help explain variability in productivity of households with relatively large crop area per capita. Vegetable production has a negative impact on land productivity in terms of energy: indeed, growing vegetables means using a portion of the land area for less caloric products than cereals or pulses. However, vegetable production usually occurs during the dry season, so it does not compete with main crops and generates income at a critical time of the year.

Based on these calculations, we can estimate what an increase in adoption of these practices would mean for productivity (Fig. 2). The intensity of practice is based on hypothetical changes compared to the average current level, given the current practices of each household type. For example, if Type II had an average of nine small ruminants per household, an intensity increase of 50 % would result in a herd of 13.5 small ruminants per household. If, for example, the adoption rate increased 30 %, productivity per unit ha would increase by 5 % for Type I, by 19 % for Type IV and by 30 % for Type II. Productivity of Type III (extensive farming) would not increase as there was no significant relationship between any of the adaptation options and productivity.

Discussion

Food security and intensification through agricultural adaptation strategies

Adaptation in smallholder farming systems will be crucial in the future, given the threats posed by climate change and demographic pressure on land and thereof food security levels. Our study shows that the adoption of so-called adaptation strategies is currently already widespread: agricultural practices that include agroforestry, soil fertility management, livestock herding (small ruminants), and crop diversification all have a significant impact on the productivity of market-oriented households. Adoption rates vary widely and depend on household type. Our across-site household typology groups farm characteristics and adoption of agricultural adaptation strategies. The four types

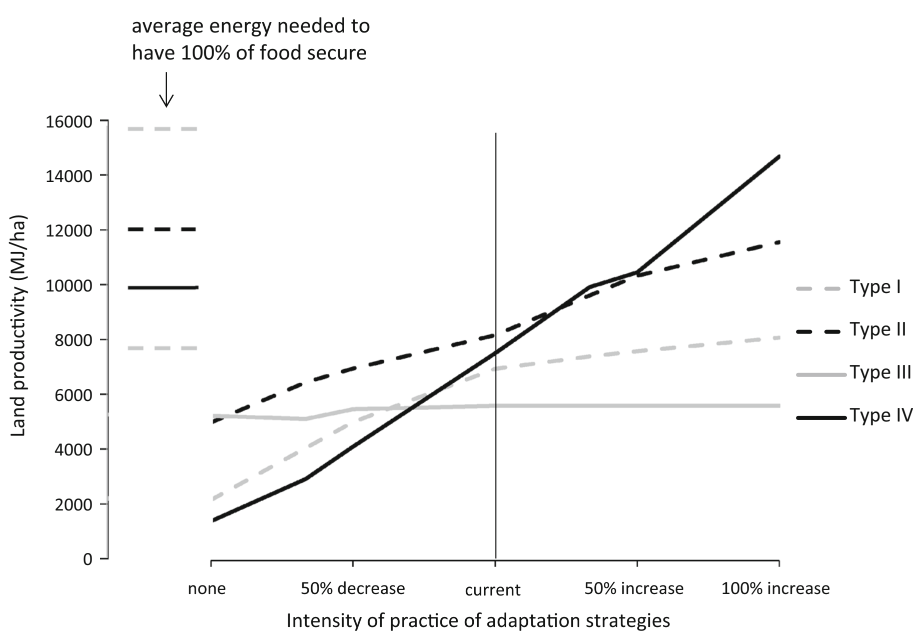


Fig. 2 Relationship between land productivity and intensity of agricultural adaptation strategies for each household type based on their current levels of practice and choices of agricultural adaptation strategies, and level of production needed to achieve food security

(Type I: Subsistence farming; Type II: Diversified farming; Type III: Extensive farming; and Type IV: Intensified farming) show strong differences in productivity and intensity of practice. Analyses of land productivity and adoption of adaptation strategies suggest that productivity increases up to threefold can be achieved for Types II and IV. To become food-secure, food-insecure households of each type must increase their productivity by 70, 64, 39 and 32 % for Types I, II, III and IV, respectively, assuming that all additional energy produced is consumed. By increasing their adoption of adaptation strategies by roughly 100 and 50 %, respectively, Types II and IV (diversified and intensified farming) can reach this goal. However, Types I and III (subsistence and extensive farming) will not reach the required level of productivity even with full adoption of agricultural adaptation strategies (Table 2). We therefore have to partly reject our hypothesis and restate it as: adoption of agricultural adaptation strategies does improve the food security status of some household types, but not all. Given the high heterogeneity (composition, land area per capita, assets, incomes, orientation to markets, etc.) of households at a community level, targeting the right agricultural adaptation strategies to different household types remains a big challenge. Understanding households' coping strategies and mechanisms as well as their agricultural and livelihood decision-making processes are of utmost importance to provide them with tailored sets of adaptation strategies and agro-advisories to make the most of these strategies within the context of climate variability and change. Availability and access of such information by agricultural innovation systems actors and other stakeholders are crucial for promoting evidence-based decision-making related to policy formulation and planning.

The key drivers of food security (i.e. food availability, as defined earlier) identified in this study are land area per capita and land productivity. Given that land area per capita is not likely to increase in the future, this study confirms the need for intensification as major adaptation strategy, as recognized by numerous authors (e.g. Jarvis et al. 2011; Vermeulen et al. 2012; Thornton and Herrero 2014). The strategies having a positive and significant effect on land productivity differed by household type in their nature and in the magnitude of their effects (Table 2). Effects are stronger for market-oriented households, which supports the findings of other authors that proximity to markets, information sources and rural advisory services are important to trigger and facilitate successful adaptation at the household level (Challinor et al. 2007; Silvestri et al. 2012).

Although various studies suggest that adaptation is progressive and that transformational adaptation happens when incremental adaptation is not sufficient (Jarvis et al. 2011; Kates et al. 2012; Rickards and Howden 2012), our study shows that these types of adaptations happen simultaneously at household level as they try to improve various aspects of their livelihoods opportunistically. A household that invests in new seeds and small ruminants (incremental adaptation) may also try to pursue seasonal migration or other off-farm income options (transformational adaptation). Two years after the survey, some of the surveyed farmers mentioned that some transformational adaptation strategies were adopted due to external events, such as new off-farm income opportunities in the neighbourhood (gold mining for example), labour shortages, unforeseen expenses (e.g. health-related). These factors change the basket of adaptation options, temporarily or permanently, embedding changes in household behaviour and decision-making that help or hinder climate change adaptation in longer-term uncertain processes (Vermeulen et al. 2013).

Stabilizing cash flow against vulnerability

The four household types had significantly different levels of food security: our analyses show that the proportion of food-secure households increases from Type I—subsistence (30 %) to Type IV—intensified (59 %), and this is, together with other determining factors, also linked to adoption of adaptation strategies. To explain the dynamics behind the food security status, we estimated cumulative monthly cash flows per household type (Fig. 3). In-flows consist of off-farm income and income from trees (all year long), and income from livestock and crops (seasonal) revenues. Out-flows consist of off-farm expenses (all year long), and expenses for livestock, land preparation and agricultural inputs (seasonal). The graph starts at harvest, when cash in-flows are highest, and shows how levels of income fluctuate throughout the year until the next harvest period. At the end of the year, before getting income from the new harvest, the diversified and intensified households improve their earnings with an increase from 360 to 640 USD for Type II and 990 to 1040 USD for Type IV, while at the same time, the subsistence (Type I) and extensive (Type III) groups show a decrease from 130 to 40 USD and 300 to 150 USD, respectively. A positive balance between in and out off-farm cash flows, as well as income from ruminants (up to 250 USD), and to a lesser extent from small ruminants (around 100 USD), maintains positive cash flows for Types II and IV during the dry season. High income from vegetable production in the dry season (145 and 215 USD for Types II and IV, respectively) allows households to make investments in crop inputs at the beginning of the rainy season (around 200 USD for large areas and around 80 USD for small areas) and get through the shortage period (July–October) by purchasing food.

The most interesting difference in cash flow occurs between the diverse and extensive farming household types (i.e. Types II and III). Whereas Type II focuses on income

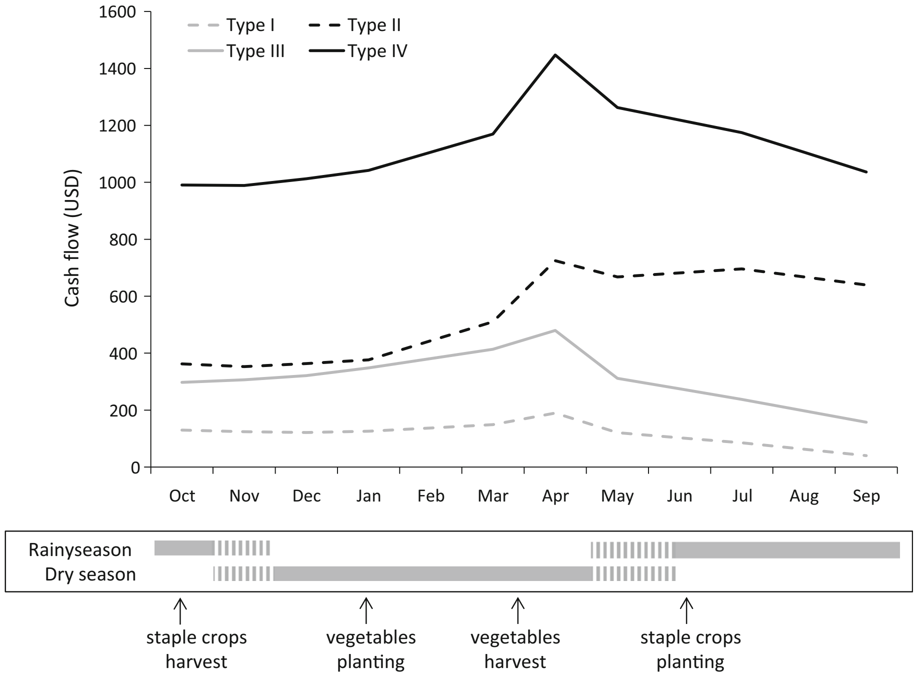


Fig. 3 Estimation of the monthly cumulative cash flow for each type of household and simplified cropping calendar

generation, the more extensive households (Type III) produce food for home consumption. This may be enough to survive in a regular year, but they may not be able to cope if there are adaptations to implement to deal with external factors, or if there are unexpected expenses. By relying essentially on their own land for food consumption, these households will be particularly vulnerable in the face of a changing climate. In addition, Type III households have few productive assets (Figure SM3), another indicator of vulnerability (Carter and Barrett 2006). In contrast, the more market-oriented Type II households have more income, which diminishes subsistence as the primary goal (Ellis and Freeman 2004): their priority becomes insuring sufficient income levels.

Analysis of cash flows per household type also highlights the importance of off-farm income: the average monthly contribution of off-farm income to absolute cash flow is around 35 % for all types. Therefore, although off-farm income did not affect food security positively per se (Table 1), it stabilizes cash flow providing a buffer to reduce vulnerability. Other studies show that there is a positive relationship between off-farm income and household welfare, in absolute terms (Barrett et al. 2001). In risky climates, households with more diversified off-farm income sources are less vulnerable to food insecurity (Reardon et al. 1992). Although one might think that households relying mainly on off-farm income for their livelihoods might not be willing to invest much effort in agricultural innovations and adaptations, it all depends on the type of off-farm income: remittances from migration of household members may enable households to overcome entry barriers to high-return but low labour-intensity activities (Wouterse and Taylor 2008).

As mentioned above, Types I and III households may not achieve food security given their current characteristics and set of management strategies. They adopted similar strategies as did Types II and IV households, as shown in Figure SM3, but may have difficulties in increasing adoption of more appropriate adaptation options due to limitations in their adaptive capacity, defined as the capacity to modify exposure to risks, absorb and recover from losses, and exploit new opportunities (Adger and Vincent 2005; Jarvis et al. 2011). For example, lack of capital, as well as lack of access to knowledge and information, have been mentioned as major barriers to adoption of agricultural adaptation strategies in sub-Saharan Africa (Bryan et al. 2009, 2013; Deressa et al. 2009; Silvestri et al. 2012), together with the presence of behavioural barriers (García de Jalón et al. 2014). In West Africa, the farmers owning more assets are more likely to take up new agricultural management practices, which demand typically large investments (Abdulai and CroleRees 2001; Wood et al. 2014). Indeed, Types II and IV have 3–9 times larger net income per capita than Types I and III, and therefore, fewer barriers to adoption and successful implementation of the practices. Types I and III seem to have a lower adaptive capacity, contributing to their higher vulnerability.

Conclusions

Our results show that there are no one-size-fits-all solutions and that for different smallholder farmers different adaptation strategies will be 'climate-smart'. Land size and market orientation are the key drivers for food security. These farms might not be large enough in the future taking into account current predictions of yield decline in West Africa. Although less food secure, households prioritizing income over food consumption are less vulnerable. Our analyses show that adaptation strategies improve the food security status of some household types, but not all. Only diversified and intensified household types can meet their food needs by increasing their current practice of adaptation strategies. Other farmers will have to switch type or change their livelihood strategies as climate and demographic conditions evolve.

The typology developed in this study gives a good entry point to analyse which interventions should be targeted to which groups of smallholder farmers, and quantifies the effect of different adaptation options on household-level food security, thereby helping to assess their effectiveness. Subsequently, it will be crucial to empower farmers to access, test and modify these adaptation options, if we are to achieve higher levels of food security.

Acknowledgments We warmly thank the 600 survey participants for their time and responses during the long hours of the interviews, and the 20 enumerators and data entry clerks who conducted the household survey in the three countries. We gratefully acknowledge the assistance in cleaning the data base by four students. CCAFS is funded by the CGIAR Fund, AusAid, Danish International Development Agency, Environment Canada, Instituto de Investigação Científica Tropical, Irish Aid, Netherlands Ministry of Foreign Affairs, Swiss Agency for Development and Cooperation, UK Aid, and the European Union, with technical support from the International Fund for Agricultural Development.

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