

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

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32 **LINKING AGRICULTURAL ADAPTATION STRATEGIES, FOOD SECURITY AND VULNERABILITY: EVIDENCE**
33 **FROM WEST AFRICA**

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35

36 **Abstract**

37

38 Adaptation strategies to reduce smallholder farmers' vulnerability to climate variability and seasonality
39 are needed given the frequency of extreme weather events predicted to increase during the next
40 decades in Sub-Saharan Africa, particularly in West Africa. We explored the linkages between selected
41 agricultural adaptation strategies (crop diversity, soil and water conservation, trees on farm, small
42 ruminants, improved crop varieties, fertilizers), food security, farm household characteristics and farm
43 productivity in three contrasting agro-ecological sites in West Africa (Burkina Faso, Ghana and Senegal).
44 Differences in land area per capita and land productivity largely explained the variation in food security
45 across sites. Based on land size and market orientation, four household types were distinguished
46 (subsistence, diversified, extensive, intensified), with contrasting levels of food security and agricultural
47 adaptation strategies. Income increased steadily with land size, and both income and land productivity
48 increased with degree of market orientation. The adoption of agricultural adaptation strategies was
49 widespread, although the intensity of practice varied across household types. Adaptation strategies
50 improve the food security status of some households, but not all. Some strategies had a significant
51 positive impact on land productivity, while others reduced vulnerability resulting in a more stable cash
52 flow throughout the year. Our results show that for different household types, different adaptation
53 strategies may be 'climate-smart'. The typology developed in this study gives a good entry point to
54 analyse which practices should be targeted to which type of smallholder farmers, and quantifies the
55 effect of adaptation options on household food security. Subsequently, it will be crucial to empower
56 farmers to access, test and modify these adaptation options, if they were to achieve higher levels of
57 food security.

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60 **Key words**

61 Adaptation strategies; Climate variability and change; Income; Land productivity; Market orientation;
62 Typology.

63

64 **1. INTRODUCTION**

65

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

73

74 West Africa is a particularly vulnerable region due in general to the low adaptive capacity of rural
75 households and the exposure to natural and anthropogenic threats (Sissoko et al., 2011). Changes in
76 behaviour and agricultural practices in order to adapt to a changing climate are seen as critical to
77 improve livelihoods and food security for millions of rural households in the region (van de Giesen et al.,
78 2010; Vermeulen et al., 2012). Most of the agricultural adaptation strategies suggested in the literature
79 are not new, but have been evolving from traditional practices and/or have been promoted decades ago
80 in response to major drought events (Dugué et al., 1993; Mortimore and Adams, 2001). Soil and water
81 conservation (SWC) practices allow increasing soil water content and maintaining humidity during dry
82 spells through an improved soil structure (Rockström et al., 2002). Trees can provide shade, biomass and
83 an additional source of income (i.e. fuel wood, charcoal) during the dry season (Akinnifesi et al., 2008),
84 as well as numerous ecological functions (Lasco et al., 2014). Vegetable production, or market
85 gardening, is a dry season strategy, to take advantage of the available labour force and make use of
86 small reservoirs and wells to produce vegetables when prices are higher (Barbier et al., 2009). Small
87 ruminants provide insurance and a substantial source of income, and help spread income risk
88 (McDermott et al., 2010). Crop diversity is a strategy for risk avoidance due to sharp fluctuations in crop
89 yield or prices (Van Noordwijk and Van Andel, 1988; Ellis, 2000). The application of mineral fertilizer
90 increases yields, allowing farmers to build up food/financial reserves. Improved varieties (drought
91 tolerant and/or short cycle) allow for increased productivity even during dry seasons (Lobell et al.,
92 2008).

93

94 Despite the upsurge in the promotion of such adaptation strategies in recent years, there is surprisingly
95 a lack of thorough analyses of their impacts on food security. We conducted a comprehensive survey in

96 three contrasting sites to capture detailed information at household-level on farm resources, farm
97 management strategies, farm productivity, food consumption and household economics. The objectives
98 were (i) to define food secure and food insecure household profiles, (ii) to explore the linkages between
99 households characteristics and adoption of seven agricultural adaptation strategies and iii) to assess the
100 impact of these strategies on food security and farm productivity. Our hypothesis was that adoption of
101 agricultural adaptation strategies makes a significant contribution to household level food security for all
102 farm households, although we expect differences between farm households on the type of strategies
103 adopted.

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106 **2. METHODS**

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108 **2.1. Site characteristics**

109

110 The study was conducted in 2012 at sites in Burkina Faso (Yatenga), Ghana (Lawra-Jirapa, referred to in
111 the text as Lawra), and Senegal (Kaffrine). These sites were identified in 2010 as benchmark sites of the
112 CGIAR research program on Climate Change, Agriculture and Food Security (www.ccafs.cgiar.org). The
113 sites, square blocks of 30 x 30 km in Burkina Faso and Senegal, and of 10 x 10 km in Ghana, were chosen
114 in a participatory approach with different stakeholders (National Agricultural Research Centers, NGOs,
115 government agents and farmers' organizations) using criteria such as poverty levels, vulnerability to
116 climate change, key biophysical, climatic and agro-ecological gradients, agricultural production systems,
117 and partnerships, etc. (Förch et al., 2011). A brief summary of climate, farming systems and major
118 resource constraints at each of the sites is presented in the Supplementary Materials (Table SM1),
119 whereas detailed descriptions are given by Sijmons et al. (2013c; 2013b; 2013a). These sites are also hot
120 spots of climate change and food insecurity as identified by Ericksen et al. (2011).

121

122 **2.2. Sampling strategy and survey implementation**

123

124 For this study, we surveyed 600 households (200 per site) using a stratified sampling strategy and
125 'IMPACTlite' survey methodology described in detail in Rufino et al. (2012). The data is available online
126 at <https://thedata.harvard.edu/dvn/dv/CCAFSbaseline/> (Silvestri et al., 2014). The first layer of the
127 sampling strategy consisted in identifying key agricultural production systems within each of the CCAFS

128 sites. High-resolution satellite images, transect drives, and interviews with local experts and key
129 informants were used to identify these production systems. Within each of the identified production
130 systems, representative villages were randomly selected up to a total of 20 villages per site. In each
131 village, 10 households were randomly selected from a list of all households. All households were
132 interviewed using a questionnaire that included information on: detailed household composition and
133 structure, crop and livestock production and management, household economy (assets, incomes and
134 expenses) and food consumption.

135

136 **2.3. Conceptual framework: indicators measured**

137

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

142

143 2.3.1. Food security and food self-sufficiency

144

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

$$155 \text{ SSR} = \frac{\sum_{i=1}^n (\text{QF}_i * E_i)}{\sum_{k=1}^h \text{ER}_k}$$

$$156 \text{ FSR} = \frac{\sum_{i=1}^n (\text{QF}_i * E_i) + \sum_{j=1}^m (\text{QP}_j * E_j)}{\sum_{k=1}^h \text{ER}_k}$$

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

161
162 The ratios were calculated on an annual basis. Quantities consumed per year were calculated from the
163 quantities consumed per month during the good and bad periods and multiplied by the length in
164 months of the respective periods. Daily energy requirements for each gender and age group, using
165 World Health Organization standards (FAO, 2004), were summed and multiplied by 365.

166 167 2.3.2. Assets

168
169 Assets are a key indicator of the degree of poverty (Carter and Barrett, 2006); households with more
170 assets are more likely to adopt new agricultural practices (Wood et al., 2014). Asset indices were
171 calculated as the sum of the number of assets, weighted by type and age of the asset, following Njuki et
172 al. (2011). Domestic assets (radio, cooker, cell phones, etc.), transport-related assets (bicycle,
173 motorbike, etc) and agricultural productive assets (hoes, ploughs, pumps, etc.) were distinguished.
174 Productive assets enhance a household's capacity to produce food. Transport assets aid access to
175 markets and make it easier to attend meetings and events and thus access information and social
176 networks, as do domestic assets such as cellphones (Kassie et al., 2014).

177 178 2.3.3. Income

179
180 Total net income was calculated as the sum of annual net farm income (gross income from sales of
181 livestock and crops minus production costs) and annual net off-farm income (off-farm earnings minus
182 related expenses). Income from crop production includes incomes from sale of crop products, crop
183 residues and plot rental. Off-farm income from sources such as artisanal work, commerce, gold mining,
184 wage employment and remittances contribute to buffer production risks associated with climate
185 variability, and to stabilize cash flows and food consumption (Brown et al., 1994). Gross income was
186 divided into its various components to calculate the percent contribution of the various activities to total
187 income. The value of agricultural products kept for home consumption purposes was not included in
188 this analysis, so what we are considering here is in effect cash income earnings of households.

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2.3.4. 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.

2.3.5. 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.

$$MO = \frac{\sum_{i=1}^n (QC_{s_i} * CE_i) + \sum_{j=1}^m (QL_{s_j} * CE_j)}{\sum_{i=1}^k (QC_{p_i} * CE_i) + \sum_{j=1}^l (QL_{p_j} * CE_j)}$$

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 liter); QCp and QLp are the quantity of crop and livestock product i and j produced on-farm (kg or liter); and CE_i and CE_j are the cash equivalent of product i and j (USD kg⁻¹ or liter).

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).

2.3.6. Agricultural adaptation strategies

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

231
232 Adaptation options that are implemented at community level, for example reforestation, use of
233 improved forages in grazing area, and development and use of communal water basins/ponds were not
234 considered in this household-level study because communal resources were not included. Neither did
235 we include non-biophysical adaptation practices such as farmer involvement of local self-help or savings
236 groups, farmer involvement in insurance schemes and farmer investments in creating off-farm income
237 opportunities (e.g. through schooling of their children).

238

239 **2.4. Data analysis**

240
241 The relationships between household characteristics and adaptation strategies were explored using
242 various univariate and multivariate techniques. Generalized linear models were fitted for food security
243 and farm characteristics for all sites. The best model structure was selected by model averaging and the
244 Aikake information criterion, using the package AICcmodavg in R (R development Core Team, 2007).
245 Then, based on the key explanatory variables for food security and adoption of adaptation strategies, a
246 household typology was developed (details below in section 3.2.2), and tested by performing a
247 canonical analysis on principal coordinates, using the CAP program (Anderson 2004)..Linear multiple
248 regressions were performed to assess the contribution of agricultural adaptation strategies to

249 productivity for each type of household. The significance level chosen was $P = 0.05$. Kruskal-Wallis tests
250 were used to assess significant differences ($P < 0.05$) between types of households.

251

252

253 **3. RESULTS**

254

255 **3.1. Household food security**

256

257 3.1.1 Food security status and contributions to income

258

259 The proportion of food secure households per site was 48%, 18% and 55% in Kaffrine (Senegal), Lawra
260 (Ghana) and Yatenga (Burkina Faso), respectively. The characteristics, agricultural adaptation strategies
261 and the average contributions of various activities to gross (cash) income for food secure and food
262 insecure households in the three sites are given in the Supplementary Materials (Figure SM1 and Table
263 SM3). Sales of staple crops (mainly millet, sorghum, maize, cowpea and groundnut) and off-farm
264 earnings made up the majority of households' gross income in all sites. Despite being the main
265 contributor to food security, cereals were sold by the food insecure households, although in a lower
266 proportion than by the food secure in Kaffrine and Lawra. At all sites, the food secure households
267 obtained more income from livestock than the insecure ones, with livestock making up to 25% of
268 income in Yatenga.

269

270 **3.2. Food security and agricultural adaptation strategies**

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272 3.2.1. Factors explaining variation in food security

273

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

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281 3.2.2. Typology of households practicing adaptation strategies

282

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

297

298 This typology shows significant differences between the adoption of adaptation strategies and
299 household characteristics that were not evident using multivariate analyses (results not shown). The
300 relative importance of farm household characteristics, agricultural adaptation strategies adoption
301 (presence or absence of the strategies) and agricultural adaptation strategies intensity (as defined
302 section 2.3.6) for each household type is presented in the Supplementary Materials (Figure SM3), and
303 shows that household types differ in the intensity of their practice of adaptation strategies, rather than
304 in the adoption itself. Four distinct household types can be distinguished in the analyses represented in
305 Figure 2:

306

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

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

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

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

329
330 The least food secure households (Type I) are also those who practice agricultural adaptation strategies
331 less intensively. The extensive farming type (Type III) compensates for lower land productivity and low
332 levels of agricultural adaptation strategies with a larger area per capita for staple food production, plus
333 they have a higher off-farm income that is likely providing them food security. There are many food
334 insecure households found in the diversified household category that are also pursuing agricultural
335 intensification strategies. However, the difference between food secure and food insecure households
336 in this group is not related to these strategies; more food secure household simply have higher land
337 productivity.

338
339 Farm size and market orientation and the performance indicators (land productivity and income) show a
340 positive and linear relationship in all cases, except for the relationship between land productivity and
341 total area per capita (Supplementary Materials, Figure SM4). In other words, income increases steadily
342 with land size, and both income and land productivity increase as households become more market
343 oriented.

344

345 3.2.3. Land productivity and adaptation strategies

346
347 Adoption of adaptation strategies only partially explains the variance in land productivity, with an
348 explained variance increasing from 10 to 29% from Type I to IV (Table 2). For households with low
349 market orientation (Type I and III, subsistence and extensive farming), these agricultural practices play a
350 minor determining role in land productivity (Table 2). For households with higher market orientation
351 (Type II and IV, diversified and intensified farming), a few practices contribute significantly to
352 productivity, especially small ruminants for households with small crop area per capita (Type II), while
353 diversification and vegetable production help explain variability in productivity of households with
354 relatively large crop area per capita. Vegetable production has a negative impact on land productivity in
355 terms of energy: indeed, growing vegetables means using a portion of the land area for less caloric
356 products than cereals or pulses. However, vegetable production usually occurs during the dry season, so
357 it does not compete with main crops and generates income at a critical time of the year.

358
359 Based on these calculations we can estimate what an increase in adoption of these practices would
360 mean for productivity (Figure 2). The intensity of practice is based on hypothetical changes compared to
361 the average current level, given the current practices of each household type. For example, if Type II had
362 an average of 9 small ruminants per household, an intensity increase of 50% would result in a herd of
363 13.5 small ruminants per household. If, for example, the adoption rate increased 30%, productivity per
364 unit ha would increase by 5% for Type I, by 19% for Type IV and by 30% for Type II. Productivity of Type
365 III (extensive farming) would not increase as there was no significant relationship between any of the
366 adaptation options and productivity.

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369 4. DISCUSSION

370

371 4.1. Food security and intensification through agricultural adaptation strategies

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373 Adaptation in smallholder farming systems will be crucial in the future, given the threats posed by
374 climate change and demographic pressure on land and thereof food security levels. Our study shows
375 that the adoption of so-called adaptation strategies is currently already widespread: agricultural
376 practices that include agroforestry, soil fertility management, livestock herding (small ruminants), and

377 crop diversification all have a significant impact on the productivity of market-oriented households.
378 Adoption rates vary widely and depend on household type. Our across-site household typology groups
379 farm characteristics and adoption of agricultural adaptation strategies. The four types (Type I:
380 Subsistence farming; Type II: Diversified farming; Type III: Extensive farming; and Type IV: Intensified
381 farming) show strong differences in productivity and intensity of practice. Analyses of land productivity
382 and adoption of adaptation strategies suggest that productivity increases up to three-fold can be
383 achieved for Types II and IV. To become food secure, food insecure households of each type must
384 increase their productivity by 70, 64, 39 and 32% for Types I, II, III and IV, respectively, assuming that all
385 additional energy produced is consumed. By increasing their adoption of adaptation strategies by
386 roughly 100 and 50%, respectively, Type II and IV (diversified and intensified farming) can reach this
387 goal. However, Type I and III (subsistence and extensive farming) will not reach the required level of
388 productivity even with full adoption of agricultural adaptation strategies (Table 2). We therefore have to
389 partly reject our hypothesis and restate it as: adoption of agricultural adaptation strategies does
390 improve the food security status of some household types, but not all. Given the high heterogeneity
391 (composition, land area per capita, assets, incomes, orientation to markets, etc.) of households at a
392 community level, targeting the right agricultural adaptation strategies to different household types
393 remains a big challenge. Understanding households' coping strategies and mechanisms as well as their
394 agricultural and livelihood decision making processes are of utmost importance to provide them with
395 tailored sets of adaptation strategies and agro-advisories to make the most of these strategies within
396 the context of climate variability and change. Availability and access of such information by agricultural
397 innovation systems actors and other stakeholders are crucial for promoting evidence-based decision
398 making related to policy formulation and planning.

399
400 The key drivers of food security (i.e. food availability, as defined earlier) identified in this study are land
401 area per capita and land productivity. Given that land area per capita is not likely to increase in the
402 future, this study confirms the need for intensification as major adaptation strategy, as recognized by
403 numerous authors (e.g. Jarvis et al., 2011; Vermeulen et al., 2012; Thornton and Herrero, 2014). The
404 strategies having a positive and significant effect on land productivity differed by household type in their
405 nature and in the magnitude of their effects (Table 2). Effects are stronger for market-oriented
406 households, which supports the findings of other authors that proximity to markets, information
407 sources, and rural advisory services are important to trigger and facilitate successful adaptation at the
408 household level (Challinor et al., 2007; Silvestri et al., 2012).

409

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

422

423 **4.2. Stabilizing cash flow against vulnerability**

424

425 The four household types had significantly different levels of food security: our analyses show that the
426 proportion of food secure households increases from Type I - subsistence (30%) to Type IV - intensified
427 (59%), and this is, together with other determining factors, also linked to adoption of adaptation
428 strategies. To explain the dynamics behind the food security status, we estimated cumulative monthly
429 cash flows per household type (Figure 3). In-flows consist of off-farm income and income from trees (all
430 year long), and income from livestock and crops (seasonal) revenues. Out-flows consist of off-farm
431 expenses (all year long), and expenses for livestock, land preparation and agricultural inputs (seasonal).
432 The graph starts at harvest, when cash in-flows are highest, and shows how levels of income fluctuate
433 throughout the year until the next harvest period. At the end of the year, before getting income from
434 the new harvest, the diversified and intensified households improve their earnings with an increase
435 from 360 to 640 USD for Type II and 990 to 1040 USD for Type IV, while at the same time, the
436 subsistence (Type I) and extensive (Type III) groups show a decrease from 130 to 40 USD and 300 to 150
437 USD, respectively. A positive balance between in and out off-farm cash flows, as well as income from
438 ruminants (up to 250 USD), and to a lesser extent from small ruminants (around 100 USD), maintains
439 positive cash flows for Type II and IV during the dry season. High income from vegetable production in
440 the dry season (145 and 215 USD for Types II and IV, respectively) allows households to make

441 investments in crop inputs at the beginning of the rainy season (around 200 USD for large areas and
442 around 80 USD for small areas), and get through the shortage period (July to October) by purchasing
443 food.

444 The most interesting difference in cash flow occurs between the diverse and extensive farming
445 household types (i.e. Type II and III). Whereas Type II focuses on income generation, the more extensive
446 households (Type III) produce food for home consumption. This may be enough to survive in a regular
447 year, but they may not be able to cope if there are adaptations to implement to deal with external
448 factors, or if there are unexpected expenses. By relying essentially on their own land for food
449 consumption, these households will be particularly vulnerable in the face of a changing climate. In
450 addition, Type III households have few productive assets (Figure SM3), another indicator of vulnerability
451 (Carter and Barrett, 2006). In contrast, the more market oriented Type II households have more income,
452 which diminishes subsistence as the primary goal (Ellis and Freeman, 2004): their priority becomes
453 insuring sufficient income levels.

454
455 Analysis of cash flows per household type also highlights the importance of off-farm income: the
456 average monthly contribution of off-farm income to absolute cash flow is around 35% for all types.
457 Therefore, although off-farm income did not affect food security positively *per se* (Table 1), it stabilizes
458 cash flow providing a buffer to reduce vulnerability. Other studies show that there is a positive
459 relationship between off-farm income and household welfare, in absolute terms (Barrett et al., 2001). In
460 risky climates, households with more diversified off-farm income sources are less vulnerable to food
461 insecurity (Reardon et al., 1992). Although one might think that households relying mainly on off-farm
462 income for their livelihoods might not be willing to invest much effort in agricultural innovations and
463 adaptations, it all depends on the type of off-farm income: remittances from migration of household
464 members may enable households to overcome entry barriers to high-return but low labour-intensity
465 activities (Wouterse and Taylor, 2008).

466 As mentioned above, Type I and III households may not achieve food security given their current
467 characteristics and set of management strategies. They adopted similar strategies as did Type II and IV
468 households, as shown in Figure SM3, but may have difficulties in increasing adoption of more
469 appropriate adaptation options due to limitations in their adaptive capacity, defined as the capacity to
470 modify exposure to risks, absorb and recover from losses, and exploit new opportunities (Adger and
471 Vincent, 2005; Jarvis et al., 2011). For example, lack of capital, as well as lack of access to knowledge and
472 information, have been mentioned as major barriers to adoption of agricultural adaptation strategies in

473 Sub-Saharan Africa (Bryan et al., 2009; Deressa et al., 2009; Silvestri et al., 2012; Bryan et al., 2013),
474 together with the presence of behavioural barriers (García de Jalón et al., 2014). In West Africa, the
475 farmers owning more assets are more likely to take up new agricultural management practices, which
476 demand typically large investments (Abdulai and CroleRees, 2001; Wood et al., 2014). Indeed, Types II
477 and IV have 3 to 9 times larger net income per capita than Types I and III, and therefore fewer barriers
478 to adoption and successful implementation of the practices. Type I and III seem to have a lower adaptive
479 capacity, contributing to their higher vulnerability.

480

481

482 **5. CONCLUSIONS**

483

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

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

498

499

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501

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509

510

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672 **Figures and tables captions**

673

674 Figure 1. Household *a priori* typology based on total area per capita and market orientation, with the
675 respective household characteristics and agricultural adaptation strategies for the three sites.
676 Arrows show if the indicator for a certain type of household is higher or lower than for the other
677 types. Stars indicate the level of significance of this difference as follows: *** = $P < 0.001$; ** =
678 $P < 0.01$, * = $P < 0.05$.

679

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

683

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

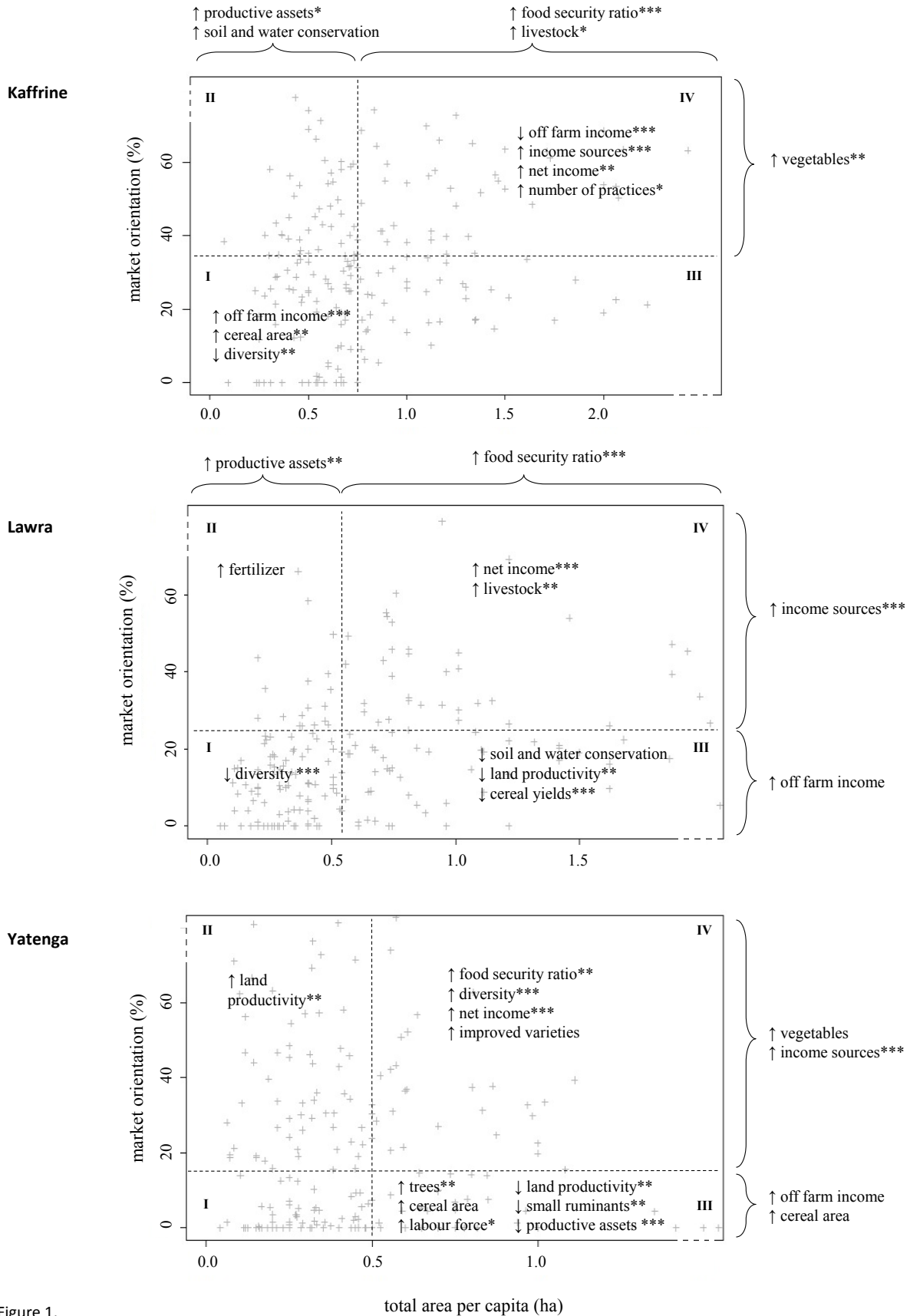
686

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

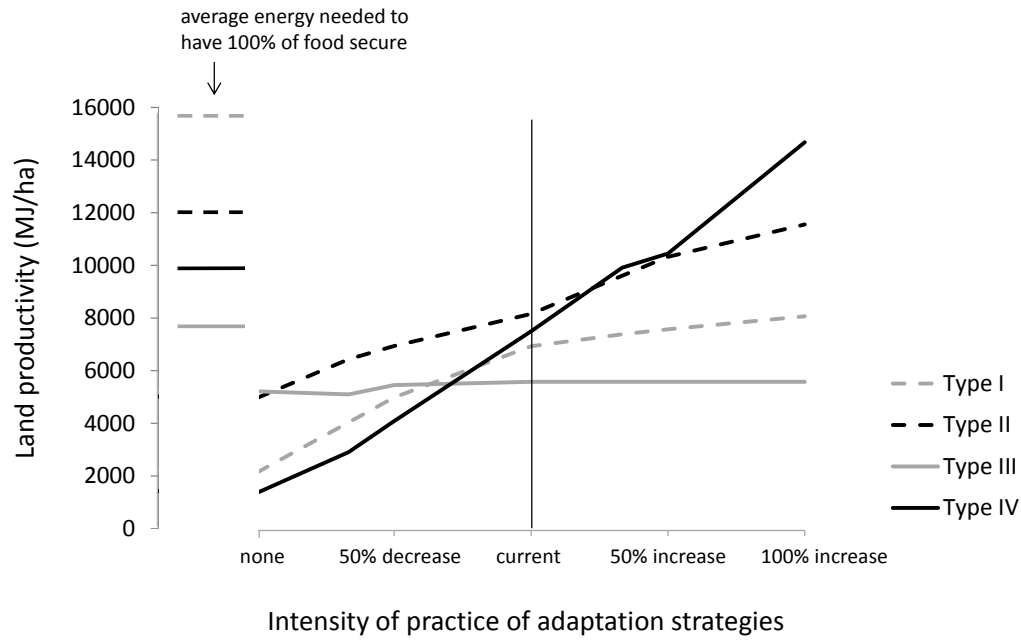
689

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

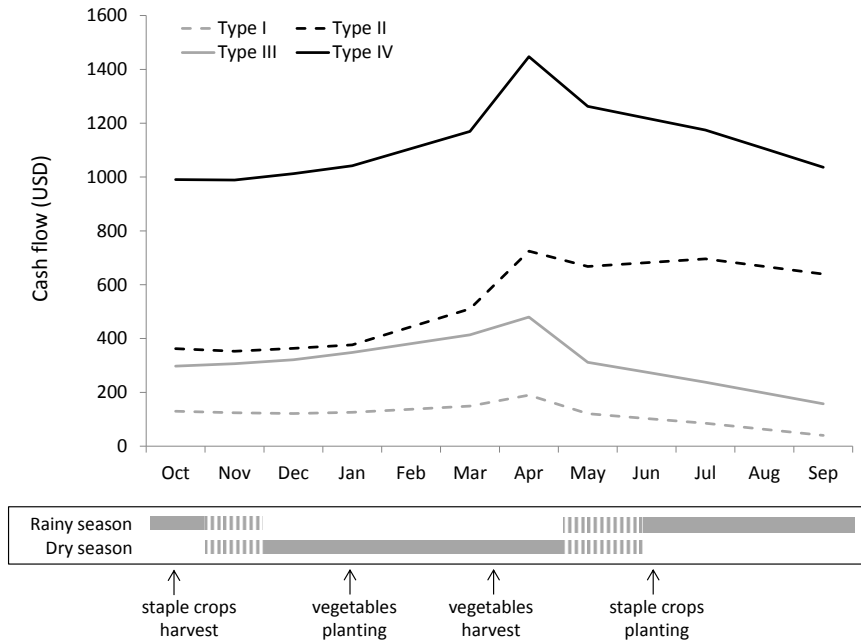
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693 Figure 1.



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695 Figure 2
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699 Figure 3
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701 Table 1.

	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 degrees of freedom

702

703

704 Table 2.

705

	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	0.14	0.14	0.29	
	P-value	0.000	0.008	0.046	0.000	0.000		

706