

## The Rural Household Multi-Indicator Survey (RHoMIS) for rapid characterisation of households to inform Climate Smart Agriculture interventions

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1 The Rural Household Multi-Indicator Survey (RHoMIS) for rapid characterisation of households to inform  
2 Climate Smart Agriculture interventions: description and applications in East Africa and Central America

3

4

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17

18 **Abstract**

19

20 Achieving climate smart agriculture depends on understanding the links between farming and livelihood  
21 practices, other possible adaptation options, and the effects on farm performance, which is conceptualised by  
22 farmers as wider than yields. Reliable indicators of farm performance are needed in order to model these  
23 links, and to therefore be able to design interventions which meet the differing needs of specific user groups.  
24 However, the lack of standardization of performance indicators has led to a wide array of tools and ad-hoc  
25 indicators which limit our ability to compare across studies and to draw general conclusions on relationships  
26 and trade-offs whereby performance indicators are shaped by farm management and the wider social-  
27 environmental context .

28

29 RHoMIS is a household survey tool designed to rapidly characterise a series of standardised indicators across  
30 the spectrum of agricultural production and market integration, nutrition, food security, poverty and GHG  
31 emissions. The survey tool takes 40-60 minutes to administer per household using a digital implementation  
32 platform. This is linked to a set of automated analysis procedures that enable immediate cross-site bench-  
33 marking and intra-site characterisation. We trialled the survey in two contrasting agro-ecosystems, in  
34 Lushoto district of Tanzania (n=151) and in the Trifinio border region of Guatemala, El Salvador and  
35 Honduras (n=285). The tool rapidly characterised variability between farming systems at landscape scales in  
36 both locations identifying key differences across the population of farm households that would be critical for  
37 targeting CSA interventions.

38

39 Our results suggest that at both sites the climate smartness of different farm strategies is clearly determined  
40 by an interaction between the characteristics of the farm household and the farm strategy. In general  
41 strategies that enabled production intensification contributed more towards the goals of climate smart  
42 agriculture on smaller farms, whereas increased market orientation was more successful on larger farms. On  
43 small farms off-farm income needs to be in place before interventions can be promoted successfully, whereas  
44 on the larger farms a choice is made between investing labour in off-farm incomes, or investing that the  
45 labour into the farm, resulting in a negative association between off-farm labour and intensification, market  
46 orientation and crop diversity on the larger farms, which is in complete opposition to the associations found  
47 for the smaller farms. The balance of indicators selected gave an adequate snap shot picture of the two sites,  
48 and allowed us to appraise the 'CSA-ness' of different existing farm strategies, within the context of other  
49 major development objectives.

50

51 *Key-words:* farm household, smallholder farming, multiple indicators, monitoring

52

53

54 **Introduction**

55

56 At present approximately 75% of the world's poor live in rural areas (Livingston et al., 2011), and many of  
57 those are in areas where climate change is expected to have a significant detrimental impact on top of current  
58 and future agricultural demand and development challenges. Predicted changes in rainfall and temperature  
59 patterns will strongly affect agricultural production, with changed crop production and yields; causing  
60 increased vulnerability of many rural communities. As much as 22% of the cultivated area under the world's  
61 most important crops is projected to experience negative impacts from climate change by 2050, with as much  
62 as 56% of the land area in sub-Saharan Africa being impacted (Campbell et al., 2011). The overall aim of  
63 CSA is to '*support efforts from the local to global levels for sustainably using agricultural systems to*  
64 *achieve food and nutrition security for all people at all times, integrating necessary adaptation and*  
65 *capturing potential mitigation*' (Lipper et al., 2014, see also Neufeldt et al., 2013). Climate smart agriculture  
66 therefore has three main pillars, to be considered at different spatial and temporal scales (FAO, 2013): 1.  
67 achieve food security, 2. adapt and build resilience to climate change and 3. reduce greenhouse gas emissions  
68 to mitigate further climate change.

69

70 There is an urgent need to improve the characterisation of agricultural systems at household level to enable  
71 more efficient assessment of capacity for adoption of climate smart measures. Capacity to adopt is  
72 intrinsically linked with the potential success of those measures, which means assessing trade-offs amongst  
73 multiple outcome objectives for adopters. Local drivers and factors need to be identified that might constrain  
74 or provide opportunities within a specified agricultural system (Carletto et al., 2015), while on the other hand  
75 generalizable standardised characteristics need to be identified that would allow robust comparisons between  
76 different systems (Frelat et al., 2016; Van Wijk, 2014). One way to assist the assessment of opportunities at  
77 smallholder farm household level for climate smart agriculture (CSA) can be through integration of  
78 standardized agricultural, poverty, nutrition and environmental indicators in the quantitative characterization  
79 of these households. This will allow us to assess how these performance indicators vary across a farm  
80 population, across different sets of farm practices present in the farm population and across different agro-  
81 ecological and socio-economic conditions as well as how they may change over time.

82 At present household level characterisation studies are hampered by a variety of problems. A recent analysis  
83 of farm household level survey data collected in different agricultural development oriented projects, showed  
84 large differences in content between different survey instruments, with lack of standardization of indicators  
85 and evidence that only a small amount of the information collected during lengthy surveys could actually be  
86 used for cross-site comparisons (Frelat et al., 2015). This lack of standardization in combination with often  
87 relatively poor data quality (Tiffen et al., 2003), generally caused by unsuitable survey design (Randall and  
88 Coast, 2015) or by biases due to perverse incentives (Sandefur and Glassman, 2015), has led to a lack of  
89 quantitative insight beyond the locality of each study regarding the effect of interactions between proposed  
90 adaptation options and the wider socio-economic and biophysical environment on household level

91 performance indicators. For example, we know little on how household food security has been affected by  
92 trends in agricultural production in different regions of the world (Carletto et al., 2013) or what the effects of  
93 adopting of CSA options are. The lack of integrated survey approaches hampers our knowledge of trade-offs  
94 and/or synergies between indicators at farm household level (e.g. Klapwijk et al., 2014), and of how these  
95 relationships and trade-offs are shaped by farm management and by social and bio-physical environments  
96 (Carletto et al., 2015; de Weerd et al., 2015).

97 In this paper we describe a new standardised modular survey tool called RHoMIS (Rural Household Multi-  
98 Indicator Survey) that tries to overcome the current problems associated with household characterization  
99 surveys. The RHoMIS tool is constructed from a set of standardised performance indicators that run across  
100 the three pillars of CSA, and aims to allow us to quantitatively analyse the links between agricultural  
101 management strategies and farm household performance. RHoMIS is designed to provide rapid  
102 characterisations of both farm practices and farm performance in order to enable i) the assessment of the  
103 ‘CSA-ness’ of different farm practices and strategies, ii) how the achievement of ‘CSA-ness’ is associated  
104 with the achievement of other household development objectives, and iii) to identify which strategies are  
105 more effective for which groups of farmers. We applied the RHoMIS tool by carrying out two surveys in  
106 contrasting sites, one in Central America and one in East Africa, and evaluated the degree to which various  
107 farming strategies contribute towards the objectives of CSA, for different types of farmers.

## 109 **Methods and Materials**

### 111 *Principles and general design of the RHoMIS tool*

112 The RHoMIS (Rural Household Multiple Indicator Survey) tool consists of a farm household survey that can  
113 be conducted on a digital platform using smart phones or tablets using the Open Data Kit (ODK) suite of  
114 software installed on Android based mobile phones or tablets (Hartung et al., 2010). Data can be directly  
115 uploaded to a web-server, and an associated set of analysis tools programmed in R extract the data and  
116 calculate indicators. The tool has been set up in such a way that additional modules of questions and  
117 indicators can be incorporated and analysed depending on the local study needs. In the supplementary  
118 material the paper version of the survey is included, while the ODK source code is available on request from  
119 the corresponding author. In the near future we will make the tools available through a website.

121 The survey tool was designed according to the following five principles:

- 122 i) the survey has to be *rapid* enough to avoid participants’ fatigue or annoyance, and keeping costs  
123 low to allow for larger sample sizes on a limited budget;
- 124 ii) the survey has to be *utilitarian*, in that all questions asked in the survey are being used in pre-  
125 defined analyses, in order to minimise superfluous data collection;
- 126 iii) the survey has to be *user-friendly*, so that all participants in the process of collecting and  
127 analysing data can perform the tasks with minimum hassle and resistance, and therefore increase

- 128 speed and data quality;
- 129 iv) the survey has to be *flexible*, so that it can be modified easily to suit the local context of the
- 130 farming systems and farm households where it will be deployed;
- 131 v) the data gathered has to be *reliable*, in that questions should be easy for respondents to
- 132 understand and the answers should be based on observable criteria or respondents' direct
- 133 experience rather than abstract scales or abstract concepts.

134

### 135 *Household Performance Indicators*

136 The indicators that are captured by the RHoMIS tool were chosen to represent important factors across the

137 agricultural production, nutrition and poverty relationships, while also capturing key indicators of interest

138 related to climate smart agriculture (i.e. greenhouse gas emissions and gender equity). The survey tool was

139 constructed in a modular way, with each module collecting the information needed to be able to calculate the

140 performance indicator of interest. New indicators of interest to the user can therefore be added easily. The

141 indicator set collected in the current version of the Rhomis tool consists of the following elements:

142

143 1) *Food availability* is supply-based estimate of the potential amount of food that can be generated through

144 on and off-farm activities by any one household, and is measured in kilo-calories (kCal) per person (male

145 adult equivalent) per day (Frelat et al., 2016; Ritzema et al., submitted; Van Wijk et al., 2014a). The

146 indicator is calculated from on-farm consumption of food crops and livestock products, and from the amount

147 of food (local staple crop) that could be purchased using the cash incomes earned through selling farm

148 produce and through off-farm activities. It ignores farm costs and household expenses, and therefore only

149 gives an indication of whether certain activities lead to enough food being potentially available to feed the

150 family, and the relative importance of these activities compared to each other. It does not quantify actual

151 consumption.

152

153 2) The *household dietary diversity score* (HDDS) is calculated according to the number of different food

154 groups consumed over a given reference period, and is a proxy indicator for diet diversity, the improvement

155 of which is associated with a number of key health indicators such as birth weight, child anthropometric

156 status, and improved haemoglobin concentrations. The HDDS score in RHoMIS follows the instructions of

157 Swindale and Bilinsky (2006) in most aspects but departs from the standard advice in terms of reference time

158 period. A 24 hour recall method is recommended, but we instead asked how often foodstuffs from each food

159 group were eaten during a 4 week period in 'the good season' and 'the bad season'; where respondents could

160 answer that they consume foods from each group either 'daily', 'weekly', 'monthly', or 'never/ less than

161 monthly'. Whilst this approach might result in lower accuracy than a 24 hour recall, the required survey

162 intensity is much less in order to capture seasonal variations. The 12 food groups used were standard, but

163 locally appropriate examples were chosen in each location. The indicator results are on a scale of 0 to 12,

164 where 12 is the most diverse diet in which all 12 food groups are eaten on at least a weekly basis. The data

165 on consumption frequency within the recall period will allow us more complex interpretations in terms of  
166 micro-nutrient use, but will not be analysed in this study.

167

168 3) The *Household Food Insecurity Access Scale (HFIAS)* indicator estimates the prevalence of food  
169 insecurity and is based on the idea that the experience of food insecurity (access to food) causes predictable  
170 reactions and responses that can be captured and quantified through a survey and summarized in a scale.  
171 There are nine questions that represent a generally increasing level of severity of food insecurity, and nine  
172 “frequency-of-occurrence” questions that are asked as a follow-up to each occurrence question to determine  
173 how often the condition occurred (Coates et al., 2007). The approach has been applied successfully in  
174 numerous studies in developing countries (Coates et al., 2006). We asked respondents about food insecurity  
175 during the worst month (‘bad season’) of the previous year, and frequency options were again ‘daily’,  
176 ‘weekly’, ‘monthly’, or ‘never/less than monthly’. The indicator is scored on a range of 0 to 27, where a  
177 higher number means a household experiences more food insecure.

178

179 4) *The Progress out of Poverty Index (PPI)* is a widely used standard indicator of poverty (Desiere et al.,  
180 2015). The PPI is a rapid ten-question survey which estimates the likelihood that a household has an  
181 expenditure below a given poverty line, where the score ranges between 0 and 100, and a higher score means  
182 a household is less likely to be below the poverty line (Grameen Foundation, 2015). The scorecard uses ten  
183 simple indicator questions based on observable household characteristics that are correlated with poverty  
184 levels using Living Standards Measurement Surveys or similar, detailed surveys. The PPI approach is now  
185 available for 55 countries, amongst which are Guatemala and Tanzania.

186

187 5) A *gender equity* indicator was included to quantify the role of women in decision-making and household  
188 resource management. The inclusion of gender in resilience and vulnerability assessments is a burgeoning  
189 topic (Smyth and Sweetman, 2015; Morchain et al., 2015), and achieving gender equity is an aim of many  
190 policies in developing countries. The indicator is constructed based on three questions asked for each farm  
191 product or income source: who does most of the work, who usually decides when to eat it, and who sells it;  
192 where the possible answers are ‘household males’, ‘household females’ and/or ‘children’. The information  
193 was aggregated to an overall score by weighing each activity along the importance it has in the *food*  
194 *availability* indicator, resulting in a final score between 0 and 1, where 1 implies that female decides  
195 completely what happens with the benefits generated by different on and off farm activities. This indicator  
196 therefore does not deal with ownership of resources, but with the agency to decide what to do with the  
197 benefits that result from these resources. We constructed a novel indicator in this case, because although  
198 alternatives do exist they were too detailed and complex for our purposes (Johnson and Diego-Rosell, 2015).  
199 For example, the Women’s Agricultural Empowerment Index requires 60-80 minutes of interview time per  
200 household (Alkire et al., 2013), which is longer than our target time for the full questionnaire.

201

202 6) Farm level estimates of *Greenhouse Gas (GHG) emissions* were calculated using the IPCC Tier 1  
203 approach (IPCC 2006). Tier 1 was chosen because it is a recognised method and has low data demands.  
204 Although the Tier 2 approach yields a more detailed GHG assessment, the substantially higher data demands  
205 can lead to unreliable data when relying on farmer recall. Key determinants of the Tier 1 estimate of  
206 emissions for this indicator are number of cattle and other livestock, land use area and type, inputs of mineral  
207 fertilizer and the production and use of manure and crop residues. The indicator does not account for carbon  
208 sinks, land use change (even if implemented longitudinally), capital infrastructure, nor farm related  
209 electricity or fuel use. Farm greenhouse gas emissions are reported in kilograms CO<sub>2</sub>-equivalent per farm per  
210 year.

211  
212 These were the six core indicators that can be quantified with this version of the RHoMIS tool. The  
213 information used to calculate these indicators was also used to calculate several other performance  
214 indicators: The questions used to calculate the Food Availability indicator were used to quantify 7) *Farm*  
215 *Productivity*, measured in total kilo-calories produced per year per hectare; 8) *Farm Produce Value*, which  
216 is the calculated total value of everything produced on the farm, using local prices and reported in US dollars  
217 per year ; 9) *Off farm income*, also expressed in 2010 equivalent US dollars, as reported by the households.  
218 Finally, the GHG emission indicator and the agricultural production component of FA (including sales and  
219 consumption) , expressed in kcal per year, were used to calculate 10) *GHG emission intensity*, expressed in  
220 in kgCO<sub>2</sub>-eq/kCal.

221

#### 222 *Performance Indicators and CSA Outcomes*

223 Performance indicators each link to one of the three pillars of climate smart agriculture: food security,  
224 adaptive capacity, and mitigation (FAO, 2013). In this way, the impacts of existing land use options, farm  
225 management practices and / or farm strategies on 'climate smartness' can be measured. By assessing  
226 household scores on each indicator, a measure of achievement towards CSA goals can be derived. The logic  
227 of this process is represented in Figure 1. Within this framework, food security is related to the indicators  
228 Food Availability, Farm Productivity, Household Food Insecurity of Access Score and Household Dietary  
229 Diversity Score. Adaptive capacity has been shown to be partially dependant on wealth (Delaney et al.,  
230 2014) and is therefore related to the PPI, Cash value of produce and also Gender Equity indicators.  
231 Mitigation is related to total GHG emissions per farm and GHG emission intensity.

232

#### 233 *Site Selection & Survey Implementation*

234 Surveys were carried out in two contrasting sites: Trifinio border region of El Salvador, Guatemala and  
235 Honduras in Central America, and the Lushoto district in Tanzania, East Africa. Agriculture and livelihoods  
236 in both sites are vulnerable to climate change. The contrasting nature of the sites aims to demonstrate the  
237 wide applicability of the RHoMIS tool. The sites were selected because they are part of a concerted data  
238 gathering effort by various ongoing research programs and projects mentioned below. Lushoto is part of the

239 Eastern Arc Mountains of East Africa which is seen as a global hotspot for biodiversity with diverse micro  
240 eco-zones within a relatively small area; mixed crop-livestock, quite intensive farming systems in higher  
241 elevation and agro-pastoral farming systems in lower elevation. The Usambara Mountains are an important  
242 source of water for northeastern Tanzania and the Pangani River is utilized for urban water supply, irrigation  
243 and hydropower generation. Deforestation, poor land management and inadequate funds for watershed  
244 management pose a threat to the long-term supply of quality water from the Usambaras to downstream  
245 communities. The supply of water might be further affected by climate change with rainfall predicted to  
246 become more irregularly distributed. The agricultural system in the Trifinio region in Central America is  
247 dominated by dry, steep land with sporadic rainfall and little to no irrigation infrastructure, where the major  
248 crops are maize and beans. Trifinio is part of the 'dry corridor' of Central America, and during the past few  
249 years rains have become more sporadic, leading to drought conditions since 2014.

250

251 In Lushoto, Tanzania, the survey was conducted on a resample of the farm households that were also  
252 surveyed in 2012 with the CCAFS research program (<https://ccafs.cgiar.org/>). In the 2012 survey 200 farm  
253 households were randomly selected within the 10 by 10km land block containing representative  
254 agroecologies in the study region that were chosen through a participatory process involving a wide range of  
255 partners and expert opinion (Kristjanson et al., 2012; Förch et al., 2014). Twenty villages within each block,  
256 and then 10 households on average within each village were randomly chosen (Kristjanson et al., 2012) for  
257 the household survey. In June 2015 150 households were randomly chosen from the 200 sampled in 2012,  
258 and they were interviewed in the first two weeks of July using the digital version of the RHoMIS survey tool.  
259 In Trifinio the survey was carried out in conjunction with the baseline survey for the USAID-funded Prueba3  
260 project, implemented by Bioversity, CATIE and Zamorano in Trifinio to test Crowdsourcing Crop  
261 Improvement (van Etten, 2011). Villages were selected by collaborating organizations as candidate villages  
262 for a bean variety introduction experiment, and a subset of 285 households was randomly selected for the  
263 RHoMIS survey from the full list of households taking part in the project.

264

265 Surveys were trialled with scientific experts in each study region; with scientific and technical staff resident  
266 in each study site; with the enumerators who would implement the surveys; and finally with rural households  
267 within the intended implementation area of the surveys. Specific changes were made on the phrasing and use  
268 of language, on local units of measurement used, on examples of locally available foodstuffs and other  
269 products (e.g. types of fertiliser), on the crops, livestock and livestock products commonly produced, routes  
270 to market, and common sources of off-farm income. The survey was conducted in Spanish in Trifinio, and in  
271 a mixture of English and Kiswahili in Lushoto.

272

### 273 *Data analysis*

274 Extraction of data and calculation of the indicators was done using scripts programmed in R. To compare  
275 values of performance indicators between the sites, and to assess the overall patterns of and co-variances

276 between the indicators in the two farm populations that were sampled correlations between the indicators and  
277 significance levels were quantified using Spearman's rank correlation. Comparisons to assess significant  
278 differences in indicator results between the two sites were performed with the Wilcoxon rank-sum test given  
279 non-normal distributions of the response variables.

280

281 A more detailed analysis to assess the climate smartness of different farming strategies was performed for  
282 both sites. We used farm size and livestock ownership as variables to define 'small' (i.e. farm land area  
283 smaller than 1 ha, and livestock ownership of less than 1 tlu) and relatively 'large' farms (i.e. farm land area  
284 larger than 1ha and livestock ownerships more than 1 tlu) and contrasted these farms in terms of their  
285 performance indicators, and in terms of the response of the performance indicators to different farm  
286 strategies. We chose to group the farms using land size and livestock numbers following the analyses of  
287 Frelat et al. (2016).

288

289 We selected three common farming strategies to appraise in terms of impact upon climate smartness:  
290 Intensification, Diversification and Market Orientation. We selected those three because they have been  
291 discussed in literature as being of potential benefit to the goals of Climate Smart Agriculture (Campbell et  
292 al., 2014). Intensification was measured in terms of quantity of nitrogenous fertiliser per ha applied to the  
293 crops by the farm household, crop diversification was measured by the number of crop species grown by a  
294 household, and market orientation was calculated by using the ratio of agricultural production sold relative to  
295 the total agricultural production (both expressed in kcal terms). Again we used simple thresholds based on  
296 the median score for each farm strategy in each site, so that households could be divided into two groups –  
297 those who score higher than average on that practice and those who score lower than average, for example  
298 high crop diversity and low crop diversity.

299

## 300 **Results**

301

### 302 *Implementation of the survey*

303 Across both sites, the running time for the survey was 40-60 minutes per household (Table 1). Gathering data  
304 for the food availability indicator took the longest, between 15 to 35 minutes, as it is based on the whole of  
305 agricultural production, sales and off farm income. The dietary diversity indicator took the second longest to  
306 complete, at around 10 minutes per household, due to the complexity of explaining the different food types,  
307 and introducing the concepts of the 'good season and 'bad season'. All other indicators only took less than 5  
308 minutes each (Table 2). The indicators were calculated successfully for most households, we were only  
309 unable to calculate less than 1% of all potential indicator data points due to lack of adequate responses.  
310 The interviewers were asked to rate the 'easiness' of gathering the data at the end of each module, whilst  
311 undertaking the surveys. Ease related to both the ease of asking and phrasing questions, and the ease of  
312 extracting the right type of response from the informant. All modules were rated as 'easy' between 50-60%

313 of the time, and rated as medium approximately 30% of the time, except for off-farm incomes, which was  
314 rated 'medium' more often than it was rated 'easy'. The Progress out of Poverty Indicator was rated as  
315 difficult only 5% of the time, and other modules rated as difficult 11-13% of the time (details shown in Table  
316 1). This provides evidence that the survey is indeed user friendly.

317 Adaptation of the survey questions, language and training of interviewers took about two weeks in both  
318 Trifinio and Lushoto. In Lushoto, Tanzania, in two weeks of data collection with 3 interviewers the  
319 responses from 150 households were collected, at a total cost of around \$5000, including the purchase of  
320 three tablets. The implementation in Trifinio was a little more complex, as the RHoMIS survey was only one  
321 of two surveys implemented as part of a larger project, so it is not possible to determine survey costs  
322 working only with RHoMIS. It does however illustrate that the tool is flexible enough to be used in  
323 conjunction with other research methods.

324

#### 325 *Indicator scores*

326 The median indicator scores in both locations are shown in Table 2, along with the interquartile range. In  
327 both sites farm sizes were generally less than one hectare, and average family size was 4 people (3.6 adult  
328 male equivalent), although with quite high variability. Livestock ownership was significantly higher in  
329 Lushoto, as well as crop diversity and intensification. The reported values of these three variables were all  
330 low in Trifinio, indicative of a basic farming system where most households grow only one crop and keep a  
331 couple of chickens. Market orientation was significantly different in the two sites, with households in  
332 Trifinio purchasing on average about 10% of their food and households in Lushoto purchasing about 30%. .  
333 Off-farm income was significantly higher in Trifinio than in Lushoto.

334

335 Food availability showed high variability between households in both locations, but median values were  
336 within the expected range (2000-4000 kcal per day per person) in Lushoto, but very high in Trifinio (median  
337 9000 kcal per day per person). The higher values in Trifinio are likely due to the predominance of maize as  
338 the main and often only crop, thereby indicating the limitations of using this indicator which only uses  
339 energy as the common denominator. Productivity, measured in Mcal per hectare per year, was similar in both  
340 sites, although there was substantially higher variability in Lushoto. Dietary diversity scores in the good  
341 season were higher in both locations than in the bad season (as would be expected), and were significantly  
342 higher in Tanzania during both seasons. Household food insecurity of access scale (HFIAS) scores indicated  
343 moderate levels of food insecurity, with greater variability in Trifinio suggesting more households  
344 experiencing severe food insecurity, although overall there was no significant difference in the median  
345 HFIAS scores between sites. Progress out of Poverty Index scores were around the lower half of the scale in  
346 both locations, indicating that approximately 50% of households could be expected to be below the \$1.25  
347 poverty line. Cash value of production is higher in Trifinio than in Lushoto, a result of higher farm gate  
348 prices, especially for beans. The gender equity indicator showed median values of 0.5 in Lushoto and 0.6 in  
349 Trifinio, which suggests an approximately equal division of responsibility between men and women in the

350 household over the use of farm produce, although there was higher variability in the Tanzanian site.  
351 Greenhouse gas emissions and emission intensity were significantly higher in the Tanzanian site, probably  
352 due to the significantly higher livestock ownership, and also higher fertiliser use. Both sites showed high  
353 variability in GHG emissions and emission intensities.

354

#### 355 *Relationships between performance indicators*

356 In both sites, there is a high degree of co-variance between the six main household performance indicators  
357 (Table 3), demonstrating that the challenges measured by these indicators are highly interlinked. Many of the  
358 typical expected relationships were found in both locations. Higher food availability was correlated with  
359 decreased experience of food insecurity, decreased poverty, and improved dietary diversity (the latter in the  
360 bad season only though). Dietary diversity in the good and bad seasons were highly correlated. Higher food  
361 insecurity scores (i.e. more food insecure households) were correlated with worse dietary diversity in both  
362 seasons, and worse poverty status. The correlation coefficients between progress out of poverty and the food  
363 security indicators are higher in Trifinio than in Lushoto, implying stronger relationships. This might imply  
364 that wealth and off farm income (see also Table 2) is a more important route to obtaining diverse and  
365 sufficient food stuffs, where as in Tanzania agricultural production is the more important route. However, it  
366 is risky to conclude this on a single survey like this, but it shows how such an integrated, multi-indicator  
367 survey tool can generate insights that open targeted avenues for further investigation. Increased gender  
368 equity showed negative correlations with food availability, dietary diversity, and progress out of poverty,  
369 although it also showed correlation with improved HFIAS score in Trifinio. Increased greenhouse gas  
370 emissions were correlated with improved food availability, dietary diversity, and food insecurity (more and  
371 stronger correlations in Trifinio). Significant correlation coefficients are mainly in the region 0.15 to 0.35,  
372 which implies that while the indicators are co-correlated, they are not the measuring the same phenomena.

373

#### 374 *Farming strategies and their 'Climate smartness'*

375 In Lushoto (Figure 2; Table 4) intensification is associated with higher Food Availability, PPI and cash value  
376 of production, and to a smaller extent to higher GHG emissions (Figure 2a). Households who have  
377 intensified also have significantly higher market orientation and higher crop diversity (see Supplementary  
378 information), so it is important to note that the three strategies are not independent. On large farms,  
379 intensification is also linked to significant increases in Productivity and Value of farm produce, while being  
380 related to significant decreases in GHG intensity and gender equity. On small farms it is linked to improved  
381 HFIAS and dietary diversity scores and is associated with higher off farm income. Increased crop diversity  
382 shows very similar relationships with the performance indicators as intensification in Lushoto, except that  
383 the effects of increased crop diversity on the important food security indicators HDDs and HFAs is still  
384 more pronounced (Figure 2b). So this indicates that intensification without increasing crop diversity not  
385 necessarily leads to the same positive effects on diets and food security as with increased diversification.  
386 Increased market orientation on large farms is associated with a strong decrease in gender equity and off

387 farm income and with higher productivity, but shows no significant relationships with the other performance  
388 indicators. In small farms in Lushoto increased market orientation is associated with higher values for PPI,  
389 but also with slightly lower values for HFIAS and HDDS: the cash generated by selling produce is  
390 apparently not being spent on buying diverse food items.

391

392 In Trifinio (Figure 3; Table 4) intensification is related to higher values of PPI and HFIAS on both the small  
393 and large farms. On large farms it is also related to increased emissions, value of farm produce and  
394 productivity, while on small farms it is related to increased productivity and diet diversity. Gender equity on  
395 both farms tends to be lower with increased intensification on both farm types. Off farm income shows an  
396 opposite trend between the two farm types: higher intensification on large farms has a strongly negative  
397 association with off farm income, while on small farms there is a positive association, although it is not a  
398 very strong relation. Crop diversity effects on the performance indicators are less strong compared to  
399 intensification (Figure 3b), with farms with less crop diversity performing quite similar in terms of HFIAS,  
400 HDDS and PPI as farms with more different crops. The spider diagram 'shape' of higher crop diversity is  
401 very similar to the intensification one for large farms (Figure 3a). On small farms crop diversity, similar to  
402 the results in Lushoto, had a significantly positive relation with diet diversity, while it is also associated with  
403 increased emissions and emission intensities. Increased market orientation (Figure 3c) follows quite similar  
404 patterns again as increased intensification, although the negative relationships with off farm income are more  
405 marked on both farm types. Similar to Lushoto, increased market orientation is related to significantly lower  
406 female decision making (gender equity indicator).

407

## 408 **Discussion**

409

410 In both study sites the RHoMIS tool met our stated goals of providing rapid, user friendly, and flexible  
411 output; both in terms of ease of implementation of the survey by enumerators and by providing efficient data  
412 management and analysis. Some of the indicators could be improved upon to give more nuanced  
413 interpretations, although there is always tension between speed of survey and detail of results (e.g. Mina et  
414 al., 2008; Coates, 2013; De Weerd et al., 2015). When considering food security and nutrition there is a  
415 clear trade-off between the level of detail that can be achieved in quantifying intake of different foodstuffs of  
416 individual actors, versus the goal of obtaining a sufficiently accurate picture of the village or local eating  
417 habits. An example is the use of the household dietary diversity score (e.g. Kennedy et al., 2011). In nutrition  
418 oriented research the gold standard is (at the moment) the 24 hour recall collecting detailed information on  
419 what several individual members of a household consumed the previous 24 hours (Coates, 2013). However,  
420 this data is more time consuming to collect, plus provides only a current snapshot the nutritional situation.  
421 Several surveys per year are required to capture seasonal variation and repeat surveys to measure trends have  
422 to take place during the same season to avoid confounding effects. Our approach of asking about frequency  
423 of consumption (daily/weekly/monthly) in the 'good' and 'bad' seasons may be less accurate, but may obtain a

424 general picture much more quickly, and appeared to function well at the level of detail required for the  
425 present study, and we could take the analysis one step further by calculating approximate vitamin input from  
426 the food groups). Potential improvements to the mitigation indicators could be inclusion of the IPCC Tier 2  
427 methodology, which would allow for better evaluation of the GHG impact of livestock management and land  
428 use changes, and an evaluation of the sequestration potential of the farm system could be a useful addition  
429 (Lamb et al., 2016). Gender equity could be developed further, taking account of ownership of productive  
430 resources and household head status, allowing for more focused analysis on the relationships between food  
431 security and gender equity issues (Alkire et al, 2013, Mersha and Laerhoven, 2016). Given the modular  
432 design it is relatively straight-forward to expand the RHoMIS tool to take account of other topics, too, such  
433 as farmer motivations and attitudes to innovation and risk, or more advanced compound indicators to  
434 evaluate different types of sustainable and non-sustainable intensification.

435  
436 Overall, the standardized indicator approach allows for comparison between the two sites, which, when  
437 applied to more locations, will be useful for gaining a better understanding of the interactions between  
438 household food security and trends in agricultural production in different regions of the world (Carletto et al.,  
439 2013). Interestingly, the Trifinio site scores high on food availability and productivity (energy based  
440 indicators), but scores low on food insecurity of access and household dietary diversity. This matches the  
441 observation of ‘hidden hunger’ in Guatemala whereby sufficient calorie intake is not matched by sufficient  
442 total nutrient or micro-nutrient intake (Hoddinott et al., 2008). Diets in the study area mainly consist of  
443 maize and beans with little else. This observation is also supported by the low crop diversity score. Because  
444 improved dietary diversity scores are generally correlated with increased crop diversity, intensification and  
445 market orientation, further yield increases in this system, for example in maize, will not necessarily lead to  
446 improved nutrition and food security (Harris and Orr, 2014; Frelat et al., 2016). In addition, maize in this  
447 system are highly unpredictable, considering the drought conditions which have persisted since 2014 until  
448 the time of writing. Our results suggest that interventions should focus on increasing the diversity of crops  
449 grown, incorporating drought tolerant, marketable crops, and on empowering women to gain better control  
450 over the cash generated by the crops in order to buy more diverse food items. In Lushoto, Tanzania, farms  
451 are more diverse in terms of the crops grown and there is more livestock, all leading to (relatively) better  
452 scores on diet diversity although the total energy available from food production is far less than in  
453 Guatemala. However, the scores of the various food-oriented indicators still represent poor nutrition and  
454 moderate experience of food insecurity.

455 If we use PPI, off farm income, total value of farm produce and gender equity as indicative of adaptive  
456 capacity, another key pillar of CSA (the only one not directly captured in one of the indicators available),  
457 then both sites have fairly similar scores: no significant difference in PPI scores, a small difference in gender  
458 equity and the farms in Trifinio generating more cash value for their produce and earning more off farm  
459 income. Income from the actual sale of produce shows significant correlation with improved status of all  
460 other indicators (see Supplementary Information), and PPI shows correlation with improvements in most

461 indicators (with the exception of greenhouse gas emissions in both cases). However, gender equity in general  
462 is negatively associated with increased intensification and market orientation, and households reporting a  
463 very high score on female decision making tend to be households where no male is present, either due to  
464 death or due to working away. These households have a shortage of labour and therefore tend to score lower  
465 on income, productivity and food security, restricting their ability to intensify and produce for the market  
466 (e.g. Njuli et al., 2011), thereby resulting in barriers to adoption that are different from those of male headed  
467 households (Mersha and Van Laerhoven, 2016).

468

469 Greenhouse gas emissions rise in tandem with most of the improvements to income and food security  
470 measured in this study. This presents a central challenge for climate smart interventions which aim to  
471 simultaneously mitigate emissions and improve food security. However, the results show how farm  
472 intensification can, on larger farms, lower the greenhouse gas intensity of production. Climate smart  
473 interventions need to balance the benefits that increased fertiliser use and animal husbandry bring to food  
474 security and adaptive capacity against the additional emissions generated. From this perspective,  
475 interventions improving the efficiency of the system (such as improving nitrogen use efficiency in manures  
476 and improving feed quality to reduce methane output and livestock weight gain) are preferable compared to  
477 interventions aiming only to increase the quantity of livestock or fertiliser used. However, when considering  
478 such trade-offs, it should be kept in mind that the absolute values of emissions from these systems are still  
479 relatively low compared to agricultural systems in the developed world (e.g. Henderson et al., 2016),  
480 especially in Trifinio where little livestock is present.

481

482 Closer examination of the farms with the most and least productive resources (land and livestock) in each  
483 site showed that the climate smartness of different farm strategies or interventions is strongly influenced by  
484 the characteristics of the farm household. For example, the intensification of production using chemical  
485 fertilisers on small farms in both sites appeared to be driven by off-farm income. The off farm income in  
486 these cases not only directly affects food security positively (e.g. Otsuka and Yamano, 2006; Kristjanson et  
487 al., 2011), but is also likely to generate that bit of extra cash that supports investment in intensification of the  
488 system, with the knock-on improvements to food security. It seems that on small farms the boost of off-farm  
489 income needs to be in place before agricultural intensification (or other strategies) can be promoted  
490 successfully (see also Frelat et al., 2016). On large farms higher off farm income is associated with lower  
491 intensification, lower crop diversity and lower market orientation. This suggests that for the large farms a  
492 choice is made between investing labour in off farm incomes, or investing that the labour into the farm. This  
493 may be due to the higher labour required to manage a larger farm, or it may be that a larger farm can more  
494 easily produce the minimum requirement for subsistence, and thus the farmers feel less compelled to  
495 intensify production if they can also obtain an off-farm wage. It would be useful to find out if there are  
496 common thresholds of farm size or livestock ownership and at which household decision making changes.

497

498 **Conclusions**

499

500 The balance of indicators in the current iteration gave an adequate snap-shot of the two sites, and appraised  
501 the 'CSA-ness' of farm strategies, and could be used in a post-hoc project evaluation of specific CSA  
502 interventions. The applications are not limited to CSA, however, as the RHoMIS tool aims to be a generic  
503 indicator framework, and after specific adaptations its potential list of application possibilities is large:  
504 integrated natural resource management, integrated nutrient management, conservation agriculture, organic  
505 agriculture, integrated pest management, agroforestry, integrated soil fertility management and many others  
506 (e.g. Lambrecht et al., 2016), while it can also be used for the construction of farm types to aid the targeting  
507 of interventions across farming systems (e.g. Sakane et al., 2013; Giller et al., 2011) or generate the right  
508 inputs to be used in modelling exercises for ex-ante impact assessments (e.g. Van Wijk et al., 2014b; Herrero  
509 et al., 2014). Providing a standardised baseline provides multiple benefits but indicator standardization is a  
510 line of research that has been largely ignored in the current literature (e.g. De Weerd et al., 2015; Carletto et  
511 al., 2015).

512

513 Our results show that the climate smartness of different farm strategies or interventions not only depends on  
514 the strategy or intervention itself, but is also determined by an interaction between the characteristics of the  
515 farm household and the farm strategy (see also Coe, Sinclair, & Barrios, 2014). This finding stresses the  
516 importance of more fine-grained farm household based analyses to assess for which groups certain strategies  
517 or interventions are 'smart', and for which households they are less 'smart' (or even 'stupid'). Avoiding  
518 strategies that are inappropriate from the outset may be one of the most important uses of the RHoMIS tool,  
519 while identifying truly smart strategies will require not only ex ante analysis, but also experimentation and  
520 iterative evaluation.

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522

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738 **Figure Captions**

739

740 Figure 1. Schematic representation of the indicators gathered from the household surveys, and the  
741 analytical framework into which they are placed.

742

743 Figure 2. Farm performance scores for large and small farm types (LF and SF) , practising high and  
744 low farm intensification (HI and LI), crop diversification (HD and LD) and market orientation (HM  
745 and LM) for Lushoto, Tanzania. Abbreviations: FA is Food Availability, HFIAS is the Household  
746 Food Insecurity Access Scale, HDDS is the Household Diet Diversity Score, PPI is Progress out of  
747 Poverty Index.

748

749 Figure 3. Farm performance scores for large and small farm types (LF and SF), practising high and  
750 low farm intensification (HI and LI), crop diversification (HD and LD) and market orientation (HM  
751 and LM) for Trifinio, Central America. Abbreviations: FA is Food Availability, HFIAS is the  
752 Household Food Insecurity Access Scale, HDDS is the Household Diet Diversity Score, PPI is  
753 Progress out of Poverty Index.

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755

756 Table 1: Time taken to gather data for each indicator, and the ease of that data gathering, as rated by the interviewers during the Lushoto survey,  
 757 n=151.  
 758

<b>Module</b>	<b>Mean time needed (minutes per household)</b>	<b>Proportion of times module perceived as easy (%)</b>	<b>Proportion of times module perceived as medium (%)</b>	<b>Proportion of times module perceived as difficult (%)</b>
<b>FA</b>	15–35	56	31	13
<b>HFIAS</b>	5	54	34	12
<b>Dietary Diversity</b>	10	54	34	12
<b>PPI</b>	3-5	61	34	5
<b>Gender Equity</b>	5	61	28	11
<b>GHG Emissions</b>	5	57	32	11

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 760

761 Table 2: Results of Indicators and drivers, with units and the possible scoring ranges shown in parentheses. Significant differences between the sites  
 762 were measured using the Wilcoxon rank-sum test and indicated by the following symbols: † p<0.1; \* p<0.05; \*\* p<0.01, \*\*\* p<0.001.

763

Indicator (unit) (possible range)	Trifinio (n=285)		Lushoto (n=150)	
	Median	IQR	Median	IQR
Farm size (ha)	0.7	0.9	0.8	0.8
Livestock ownership (tlu) ***	0.2	0.3	1.2	2.2
Family Size (adult male equivalent)	3.6	2.5	3.6	2.0
Crop Diversity (number of crops grown) ***	1.0	1.0	3.0	2.0
Intensification (kg nitrogenous fertiliser per hectare) **	5.0	5.0	10.0	47.5
Market Orientation (0-1) ***	0.1	0.3	0.3	0.5
Food Availability (kcal per mae per day) ***	9922.7	20139.8	3174.3	5418.4
Farm Productivity (Mcal per hectare per year)	5104.0	5878.8	5007.8	8146.5
Household Food Insecurity Access Scale (HFIAS) (0-27)	8.0	9.0	9.0	6.0
Dietary Diversity (good season) (HDDS) (0-12) ***	7.0	4.0	9.0	3.0
Dietary Diversity (bad season) (HDDS) (0-12) ***	5.0	4.0	6.0	4.0
Progress out of Poverty Index (PPI) (0-100)	40.0	32.0	42.0	20.0
Off Farm Income (USD per year) ***	489.1	1726.6	0.0	261.5
Value of Farm Produce (USD per year)***	550.7	846.1	340.8	634.7
Gender Equity (0-1) †	0.6	0.3	0.5	0.5
GHG emissions (kgCO <sub>2</sub> -eq per household per year) ***	498.9	966.0	2761.1	5560.1
GHG intensity (kgCO <sub>2</sub> -eq per kcal) ***	0.1	0.2	0.5	1.6

764

765

766 Table 3: Correlation table between the six main household performance indicators in Trifinio and Lushoto, using Spearman's Rho correlation test. The  
 767 correlation co-efficient and significance values refer intra-site comparisons only, there are no correlations between the two sites presented in this table.  
 768 Abbreviations: FA is Food Availability, HFIAS is the Household Food Insecurity Access Scale, HDDS is the Household Diet Diversity Score, PPI is  
 769 Progress out of Poverty Index, GHGs is Greenhouse Gas emissions. Significance levels are denoted by: † p<0.1; \* p<0.05; \*\* p<0.01, \*\*\* p<0.001.  
 770

Variable name	Lushoto (n=150)						
	FA	HFIAS	HDDS (good)	HDDS (bad)	PPI	Gender Equity	GHGs
FA		-0.24**	0.11	0.21*	0.34***	-0.19*	0.27**
HFIAS	-0.19**		-0.18*	-0.31***	-0.31***	-0.02	-0.12
HDDS (good)	0.26***	-0.23***		0.51***	0.11	-0.08	0.20*
HDDS (bad)	0.22***	-0.35***	0.55***		0.18*	-0.01	0.12
PPI	0.23***	-0.51***	0.34***	0.35***		0.02	-0.04
Gender Equity	-0.05	0.10 <sup>†</sup>	-0.03	-0.15*	-0.15*		-0.21*
GHGs	0.35***	-0.33***	0.28***	0.26***	0.39***	-0.17**	

771  
772

773 Table 4. The significance of differences in performance indicators for households who do and do not score highly on farm strategies, in Lushoto and in  
 774 Trifinio. All values refer to Figures 2 and 3. Abbreviations: FA is Food Availability, HFIAS is the Household Food Insecurity Access Scale, HDDS is  
 775 the Household Diet Diversity Score, PPI is Progress out of Poverty Index, GHGs is Greenhouse Gas emissions. Significance levels are denoted by: ns  
 776 not significant, † p<0.1; \* p<0.05; \*\* p<0.01, \*\*\* p<0.001.

777

Lushoto, Tanzania	Farm Type	Practice	FA	Productivity	HFIAS	HDDS	PPI	Off Farm Income	Produce Value	Gender equity	GHG emission	GHG intensity
	Large	Intensification	ns	†	ns	ns	*	†	ns	ns	†	ns
	Small	Intensification	†	†	**	**	***	**	*	ns	**	ns
	Large	Diversity	†	†	ns	*	ns	ns	ns	ns	†	ns
	Small	Diversity	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
	Large	Market	ns	†	ns	ns	ns	ns	ns	*	ns	†
	Small	Market	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

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Trifinio	Farm Type	Practice	FA	Productivity	HFIAS	HDDS	PPI	Off Farm Income	Farm Produce Value	Gender equity	GHG emission	GHG intensity
	Large	Intensification	ns	ns	*	*	*	†	***	ns	*	ns
	Small	Intensification	ns	ns	†	ns	ns	ns	*	ns	ns	ns
	Large	Diversity	ns	*	†	ns	ns	ns	**	ns	***	ns
	Small	Diversity	ns	ns	ns	**	ns	ns	*	ns	**	*
	Large	Market	ns	†	†	**	ns	ns	**	ns	†	ns
	Small	Market	ns	**	ns	*	ns	ns	***	ns	***	ns

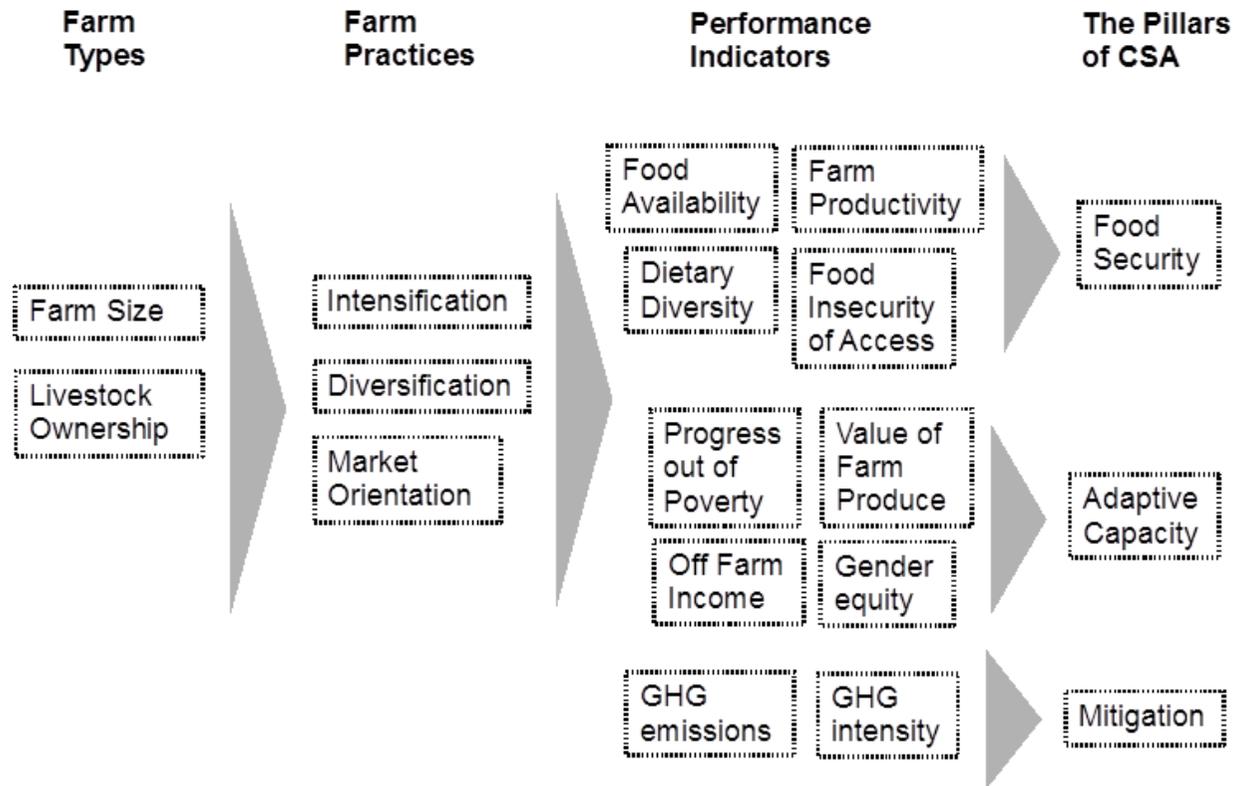
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780 Figure 1.

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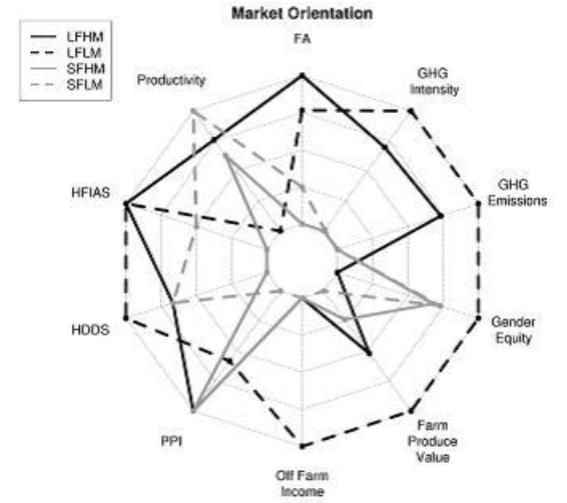
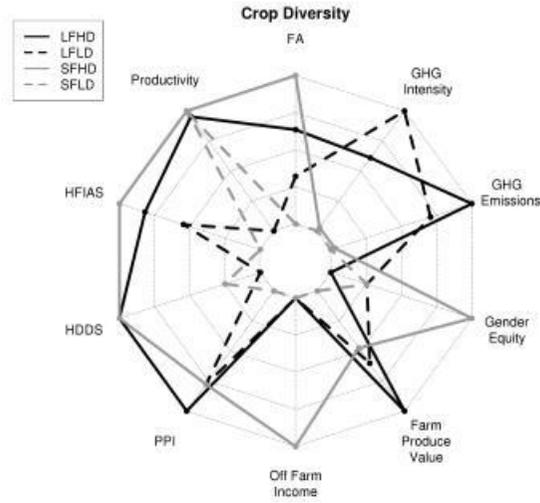
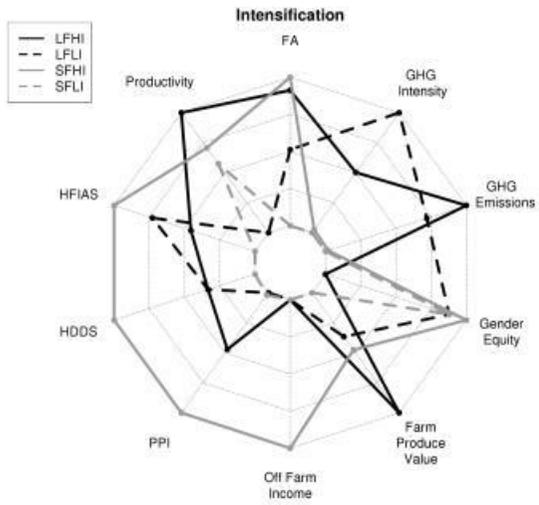
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786 Figure 2.

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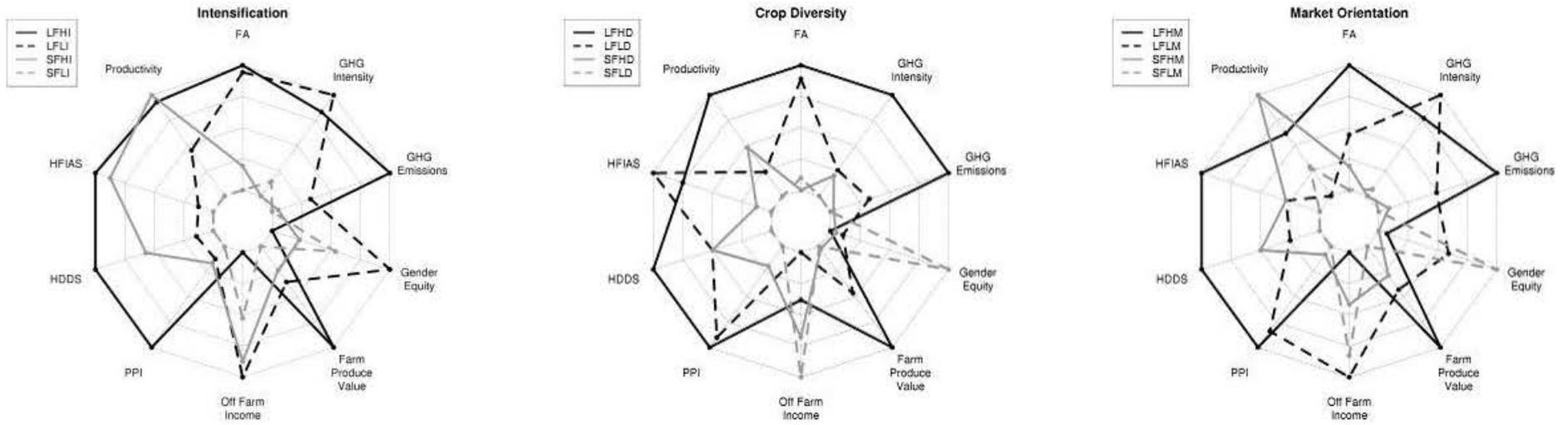
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792 Figure 3.

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