Climate Smart Agriculture: Synthesis of case studies in Ghana, Kenya and Zimbabwe

Supporting material for the presentation 'Towards a metrics for CSA' at the Global Science Conference on Climate Smart Agriculture 2015, Montpellier, France

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Business Unit Agrosystems research

Address	:	P.O. Box 616, 6700 AP Wageningen, The Netherlands
	:	Wageningen Campus, Droevendaalsesteeg 1, Wageningen, The Netherlands
Tel.	:	+31 317 48 05 59
Fax	:	+31 317 41 80 94
E-mail	:	info.pri@wur.nl
Internet	:	www.wageningenUR.nl/en/pri

Table of contents

Preface

Agriculture is particularly vulnerable to climate change, which impacts livelihoods and food security, especially that of the world's poorest people. Global food systems face the challenge to develop food systems that are able to meet the growing demand for food and biomass under changing climate conditions. Agriculture has also a role in reducing greenhouse gas emissions and lies therefore at the heart of complex challenges to be addressed.

Climate Smart Agriculture (CSA) is an integrated concept to achieve food security in the face of climate change, while also mitigating climate change and contributing to other development goals. How these goals can be combined conceptually as well practically is still being debated and elaborated. This continuing process to achieve climate inclusive agricultural planning and implementation requires a strong commitment from policy makers in government and in the private sector, including farmers and scientists (Verhagen et al., 2014). As part of this process the Montpellier Global Science Conference on CSA was organized in March, 2015 (http://csa2015.cirad.fr/index.php/csa2015). The conference addressed key research issues, gathered CSA facts and figures from developing and developed countries and supported collaborative efforts with broad social participation.

Wageningen UR was one of the organizers of this conference and several of its representatives held presentations at the various sessions. One of the presentations in the Plenary 3 session Key Questions for Climate-Smart Agriculture was on 'Towards metrics to track and assess climate smart agriculture' (Verhagen, 2015; Appendix I). This Report describes the methods and data underlying some of the results shown in this presentation during the Global Science Conference. The report is a justification of the underlying data and methods, and results presented at the Global Science Conference. In addition, some new results are presented, which have not been presented at the Global Science Conference because of time constraints. The report illustrates how CSA research questions can be addressed using a number of different methods and metrices to gain better understanding of achieving CSA objectives in different local contexts.

1. Introduction

Climate-Smart Agriculture (CSA) invites researchers, practitioners and policy makers to explore solutions combining three pillars, food security, climate change adaptation and mitigation, underpinning sustainable landscapes and food systems (http://csa2015.cirad.fr/index.php/csa2015). This is essential since the agricultural sector is facing unprecedented uncertainty and risks, but at the same it is at the heart of achieving various development objectives.

In this report we illustrate with case studies from sub Saharan Africa how different research questions relevant in the context of CSA can be addressed using a mixture of desk approaches and methods and metrices ranging from farming systems analysis, climate change scenarios to crop growth models. We describe how crop intensification under current and future climate conditions affects household food self-sufficiency, household income and greenhouse gas emissions in sub Saharan Africa (SSA). Our research builds upon previous work in which the food self-sufficiency and related land requirements and income has been analysed of 3,000 farm households in eight countries in humid and semi-arid SSA, i.e. DRC, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda and Zimbabwe (Hengsdijk et al., 2014). These household data were collected within the N2AFRICA project (www.N2Africa.org) which has the objective to increase grain legume yields, biological nitrogen fixation, and household income in different action sites of the eight countries. Using information on land assets of farm households, family food needs, local production data and prices of major inputs and outputs the food self-sufficiency levels and crop income of these households were estimated. The study of Hengsdijk et al. (2014) showed that at current crop productivity levels a large share of the households (30%) in SSA is not able to produce sufficient food to feed their own families while 50% of the households are food-self-sufficient but earn less than 1.25 USD capita^{-1} day^{-1}. Crop intensification improves the food self-sufficiency situation of most households but is not able to lift most farmers out of poverty: crop income of 50% of the households is less than 1.25 USD capita^{-1} day^{-1} while substantial cash investments by farmers and broader investments in knowledge infrastructure and human capacity are needed to achieve the higher crop yields.

This study widens the existing analyses by investigating the effect of improved N management in maize under current and future climate conditions on household food self-sufficiency, household income and greenhouse gas emission. We also look at the wider implications of food production of farm households for a growing non-farming population in SSA. As a climate smart management option, the yield effects of maize varieties adapted to future climate conditions are simulated and their contribution to farm household (FHH) objectives assessed. Instead of focussing at eight countries this study addresses three case study areas in West, South and East Africa, namely Ghana’s Northern region, Makoni region in Zimbabwe and Wamaluma in Kenya.

Chapter 2 of this report presents the major characteristics of the three case study regions. The used data and methods are summarized in Chapter 3. For a more comprehensive description of aspects related to the material and methods is referred to Hengsdijk et al. (2014). In Chapter 4 the results are presented of several research questions that have been formulated at the end of Chapter 3. In Chapter 5 conclusions are drawn.

2. Characteristics of case study areas

Table 2.1 shows the major characteristics of the three case study regions, i.e. Ghana's Northern region, Makoni region in Zimbabwe and Wamaluma in Kenya. Latter region is most humid of the three regions, 1754 mm of rainfall per year which allows growing two crops per year. It is also the most densely populated region (1200 persons km^{-2}) with on average very small land holdings (0.6 ha) and very little land available per capita (0.14 ha). The Makoni region in Zimbabwe is the driest region (863 mm $year^{-1}$) and it has the lowest population density (30 persons km^{-2}). Land holdings in Northern Ghana are largest (3.1 ha) and also land availability per capita is largest (0.61 ha). About 85% of the farm population in the household sample in the Northern region of Ghana depends for more than 75% of its income from farming, which is considerably higher than in Wamaluma and Makoni. In each case study area about 100 households have been sampled (Table 2.1).

Table 2.1 Major characteristics of the three case study regions, i.e. Ghana's Northern region, Makoni region in Zimbabwe and Wamaluma in Kenya. FHH= farm household

	Ghana Northern region	Kenya-Wamaluma	Zimbabwe-Makoni
Sample size (#FHH)	104	97	98
Number of growing seasons	1	2	1
Average annual rainfall 1981-2010 (mm)	984	1754	863
Agro-ecological zone	Tropical warm/ sub humid	Tropical cool/ humid	Tropical warm/ semi-arid
Population density (per km^2)	61-70	1200	30
Average land holding size (ha)	3.1	0.6	1.6
Average FHH size (capita)	5.1	4.2	3.8
Land availability (ha cap^{-1})	0.61	0.14	0.42
Tropical Livestock Units per FHH (#)	4.4	1.4	1.9
% female household heads	6	47	40
% FHH with income > 75% from farming	85	58	47
Number of cultivated crop types	4.4	3.5	2.9

Figure 2.1 shows the variation in the number of capita per household, landholding size and land assets per capita in the three case study areas. In general, households in Ghana tend to be largest, comprising more family members, and land holding assets (per capita) are clearly smallest in Kenia.

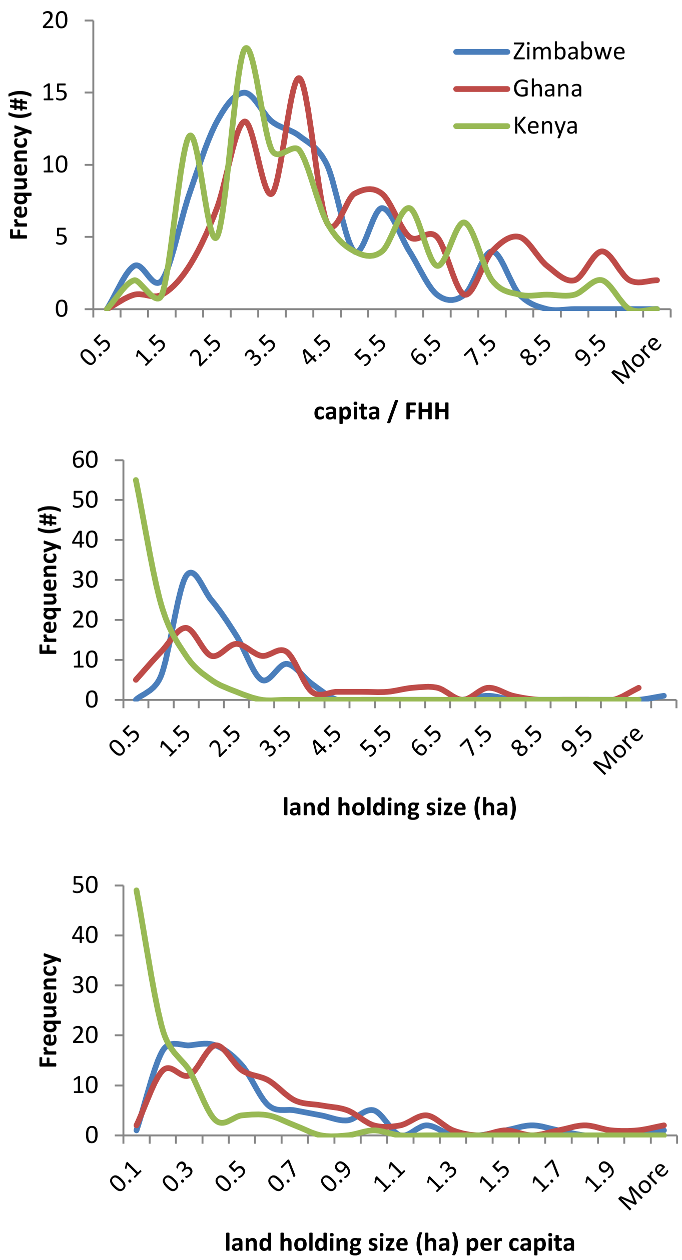


Figure 2.1 *Variation in the number of capita per households (top), size of the land holdings (centre), and land availability per capita (bottom) in the sampled households of the Northern region of Ghana, Wamaluma in Kenya and Makoni in Zimbabwe.*

3. Material and methods

We have combined information on household land assets from the three case study areas with simulated maize yield potentials under different N input levels and empirical data on yield potentials of a cash crop (soy bean) to estimate the impacts on food self-sufficiency and income of farm households under current and future climate conditions. See for a detailed description of the methodology Hengsdijk et al. (2014).

In short, the applied method is based on the land requirements to satisfy own household food (energy; 2,500 Kcal capita^{-1} day^{-1}) requirements using maize as an indicator crop. A 'land gap' is calculated for those households that cannot produce sufficient food (energy) to feed own household members, and a 'land surplus' for those households that are able to produce beyond own household (energy) needs. Subsequently, this land surplus is used for growing maize or a cash crop, for which soy bean is used as indicator crop as it can be grown in the three case study areas where it is used for generating cash income.

Crop yields

We distinguish different rain fed production levels for maize and soy bean: For maize they consist of three N input levels, a location-specific low N level, 75 and 150 kg N ha^{-1}. The location-specific (low N) level is 18 kg N ha^{-1} for Ghana, 31.5 kg N ha^{-1} for Kenya and 8 kg N ha^{-1} for Zimbabwe. These low N levels represent the input level required to maintain soil fertility and correspond with the current low maize yield levels in each case study area. As actual N levels in the case study area were unknown the location-specific (low) N levels have been derived from a calculation in which current maize yields (from statistics) have been used as target and associated N levels determined. The highest N level (150 kg N ha^{-1}) approaches 80% of the water-limited (rain fed) production level in each region. The maize yields have been simulated using the LINPAC growth model (Jing et al., 2012) and are expressed on the basis of 11% moisture content.

For soy bean we also distinguish three production levels, but these are based on empirical yield data of a large number of experiments carried out in the three case study areas (Hengsdijk et al., 2014). A low yield level corresponds with the actual situation with no external inputs, an improved yield level is realised with applying 20 kg P ha^{-1}, while an even higher yield level is achieved using 20 kg P ha^{-1} plus inoculants.

The maize simulations are done for the most dominant soil type in each case study area and for each year of the period 1991-2010 in each location. Weather data from these years were obtained from CRU (TS 3.21; http://www.cru.uea.ac.uk/data). In the case study regions is no water available for irrigation and therefore simulated maize yields indicate the rain fed yield potentials under different N levels. In Kenya are two potential growing seasons, we have only simulated maize yields for the first major rainy season and used this yield for the second season in the food self-sufficiency analysis at household level as described in Hengsdijk et al. (2014).

Climate change

In addition to yield simulations of maize for current climate conditions, future climate conditions for the period (2020-2050, indicated as 2035 in the remainder of the paper) have been constructed based on four climate models (Fig. 3.1). We have selected the results of the ccma_canesm2 model, which showed the most extreme changes for at least one climate variable (rainfall or temperature) compared to the baseline in the three case study areas (Fig. 3.1). We have used the Delta method (Wilby et al., 2004), i.e. changes in temperature are obtained by adding the temperature change to the temperature data of CRU, and changes in rainfall by multiplying the rainfall change factors with the CRU rainfall data. The simulations under future climate conditions have been carried out with characteristics of currently used maize varieties and with variety characteristics that are better suited for future climate conditions. Because of the higher temperatures in 2035, late maturity maize varieties can be grown if water is not limiting production. We have accounted for the changed temperature regime in 2035 and allowed to grow other maize varieties with higher thermal time requirements for reaching maturity than currently grown varieties in the case study areas.

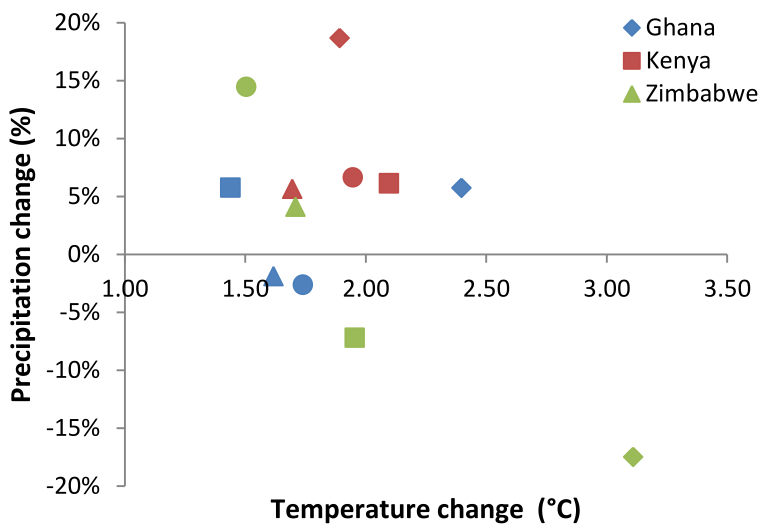


Figure 3.1 *Change in temperature and precipitation of the potential growing season in each location (blue = Ghana; red = Kenya; green = Zimbabwe) between future scenario RCP 8.5 in 2035 relative to the baseline climate in 2000 (from: http://www.ccafs-climate.org/data/). Four different climate models were used (circle = bcc_csm1_1; square = bnu_esm; triangle = cesm1_bgc; diamond = ccma_canesm2 (= selected model for this study).*

Economics of crop production

The net revenues of the production of maize and soy bean are calculated to estimate the crop income per household in each case study area. Net revenue is defined as the difference between the production times the price and the costs of production. In the case of maize the costs consists of the costs for N fertilizer (based on long-term monthly average IFDC prices for urea; http://africafertilizer.org/) and for soy bean the costs consists of seed and P fertilizers (with or without inoculum). Production costs for soy bean have been collected in the N2AFRICA project.

Greenhouse gas emissions

Associated with the different production levels we estimate greenhouse gas (GHG) emissions, which in our case relate to external N fertilizer input (100% urea) and N contained in crop residues, which remain in the field after crop harvest. We use default methods (Tier one) of the Intergovernmental Panel on Climate Change (IPCC) to calculate direct and indirect N_2O-N emissions, i.e. 1.475% of the applied external N fertilizers (*Nrate*; assuming 25% N-NH_3 volatilization of applied N) and 1.225% of the N contained in crop residues (*Nresidue*). The N_2O emission is converted into CO_2 equivalents using a global warming potential multiplication factor of 310 while accounting for the nitrogen mass on N_2O. Subsequently, the CO_2 emission due to production of urea is added:

$$GHG = (0.01475 * Nrate + 0.01225 * Nresidue) * 44/28 * 310 + 3 * Nrate$$

The total GHG emissions (in kg CO_2-eq) are expressed per kg maize produced.

Research questions

The following six research questions have been addressed, which will be elaborated in Chapter 4 of this report:

1. Food self-sufficiency analysis: At what maize yield level farm households in the three case study areas become self-sufficient in food (=energy requirements of the household members are met)? (section 4.1)
2. Food supply analysis: To what extent farm households in the three case study areas are able to feed a rapidly growing urban population in sub Saharan Africa? And what is the role of crop intensification in achieving this objective, and how does intensification affects GHG emissions? (section 4.2)
3. Income effects of growing cash crops: To what extent small farm households in the three case study areas can participate in market-led developments and what are the income effects? We use soy bean as a cash crop to study this research question. (section 4.3)

4. Effects of climate change on maize yields: how do future climate conditions affect maize yields and to what extent can climate smart variety choices alleviate yield reductions under future climate conditions? (section 4.4).
5. What is the minimum land holding size of households enabling them to gain more than the poverty benchmark? (section 4.5)
6. How much food can be produced by the household samples in each study beyond own food needs under crop intensification and changed climate conditions? (section 4.6)

4. Results

4.1 Food self-sufficiency and intensification

Based on the average land availability per capita and energy requirements per capita (2500 Kcal day^{-1}) in each case study area the minimum maize yield was calculated that is required to satisfy food self-sufficiency needs of the farm households. Figure 4.1 shows the results of the three case study areas including the average simulated maize yield levels obtained in the period 1991-2010 with location-specific low N inputs, representing current N input conditions, and a medium N level of 75 kg N ha^{-1}.

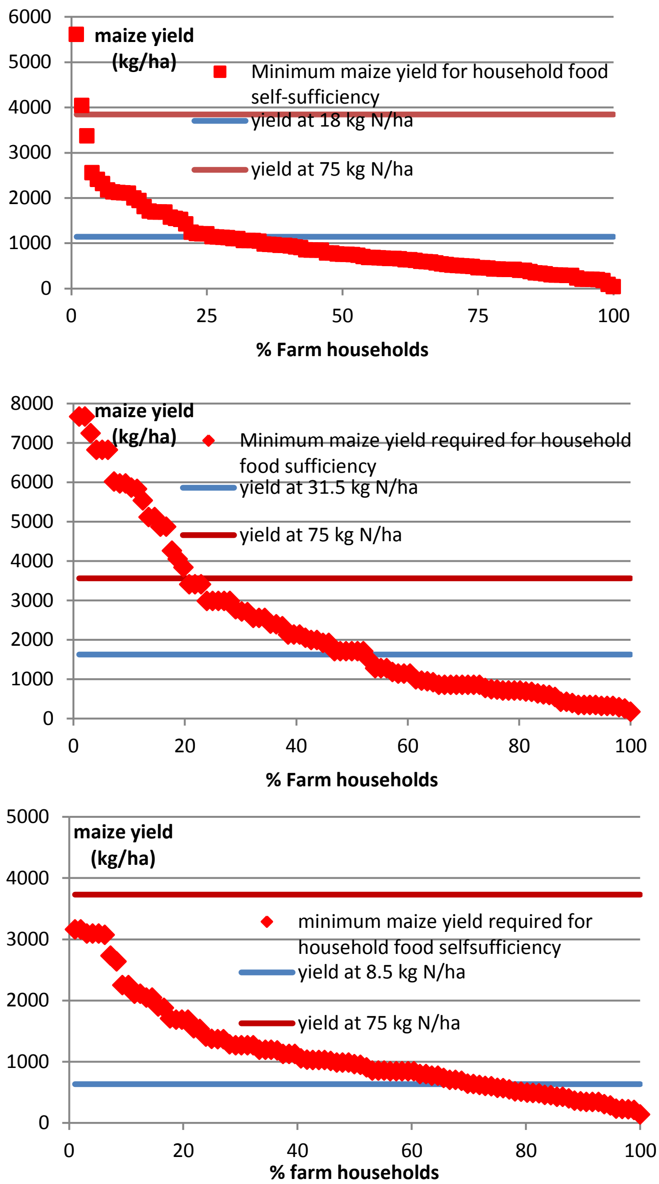


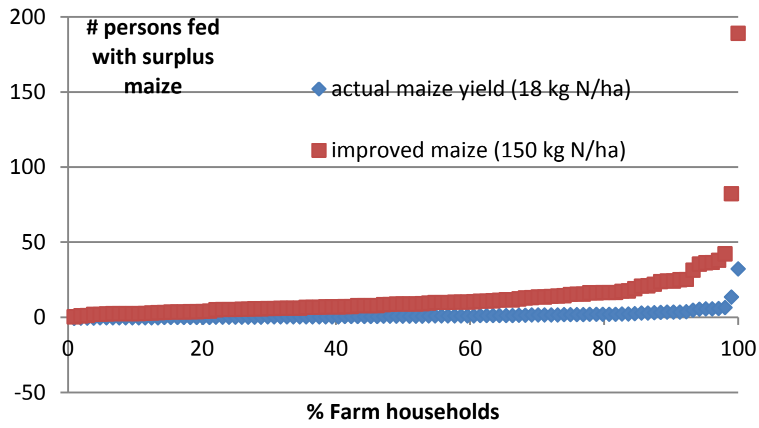
Figure 4.1 *Minimum required maize yields for achieving household food self-sufficiency, current average low location-specific yield levels and average improved yield levels obtained with 75 kg N ha^{-1}. At top figure =Ghana; centre=Kenya; bottom=Zimbabwe. Note: For reasons of visualization one data point is not shown of Zimbabwe as well as Kenya with extreme small land availabilities (0.028 and 0.025 ha capita^{-1}, respectively).*

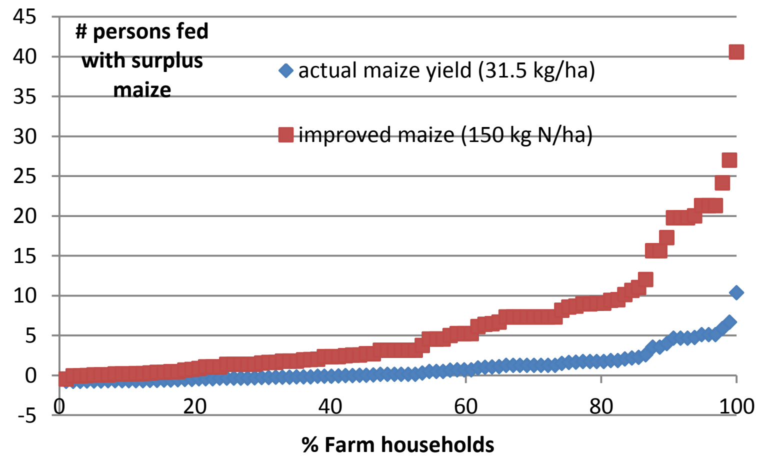
Figure 4.1 shows that in Ghana approximately 25% of the farm households produces under current conditions too little maize to satisfy own food needs, in Kenya 50% of the households and in Zimbabwe about 70%. Minimum maize yields to satisfy household energy requirements go as high as 8 t ha^{-1} in Kenya because land holdings are smallest, while in Zimbabwe land per capita ratios are more favourable and about 3 t ha^{-1} is needed to satisfy food requirements of the smallest household in our sample. While the average yield level obtained with 75 kg N ha^{-1} is sufficient to satisfy the food requirements of most households in Ghana and Zimbabwe, in Kenya this higher yield level is still insufficient for about 20% of the households to become food self-sufficient.

4.2 Food supply and intensification

With continuing urbanization of sub Saharan Africa, i.e. almost 50% of the population lives in urban areas, it is increasingly important that African agriculture is able to feed a rapidly growing urban population. In Figure 4.2 we show to what extent households in the three case study areas are able to accomplish this task. It is based on the assumption that the entire land holding of households is planted with maize under two N management scenarios, i.e. one representing the actual situation with low N inputs and related low maize yields, and one scenario with 150 kg N ha^{-1} resulting in much higher yields. The yield simulations in each case study area were done for a favourable year in which the highest actual maize yields were obtained. These years differed across the case study areas, i.e. the year 1993 in Ghana and Kenya; and 1991 in Zimbabwe.

The results are expressed in terms of the number of persons that can be fed with maize in surplus of own household needs (based on 2,500 KCal per day per capita) divided by the number of capita per household. For example, in Ghana is one household of which each family member (capita) is able to feed roughly an additional 200 other persons in the high N scenario (Fig. 4.2, top). This is an extreme case associated with a large farm (>25 ha) and high maize yields (6.9 t ha^{-1}) obtained with high external N inputs. Most households are able to feed much less persons, especially in the current situation (low N scenario). Hardly visible in Figure 4.2, but approximately 20% in Ghana, 40% in Kenya and over 60% of the households in Zimbabwe are food deficit in the current situation. The food deficit situation of household means that additional maize (energy) is needed for satisfying own household energy needs instead of being able to provide maize to a growing urban population. The shown data refer to a year with the highest actual yield in the period 1991-2010, which means that in other years the situation is worse.





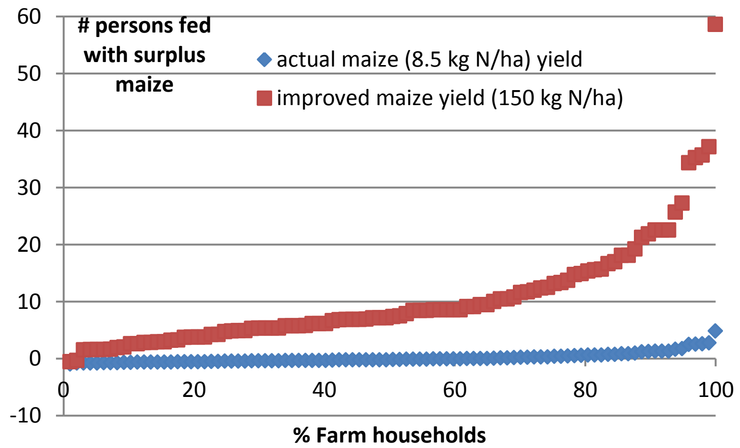


Figure 4.2 Number of extra persons that can be fed by households in the three case study areas expressed in persons per household capita, top figure =Ghana; centre=Kenya; bottom=Zimbabwe.

Intensification is helpful to improve the food self-sufficiency situation of households, and only a few percent of the households in Zimbabwe and Kenya remain food deficit, in Ghana all households produce maize beyond own family needs (Fig. 4.2). Intensification, however, results in an increase in GHG emissions in all three case study areas (Fig. 4.3). The increase in GHG is associated with high N fertilizer inputs and N rich crop residues that remain in the field after harvest.

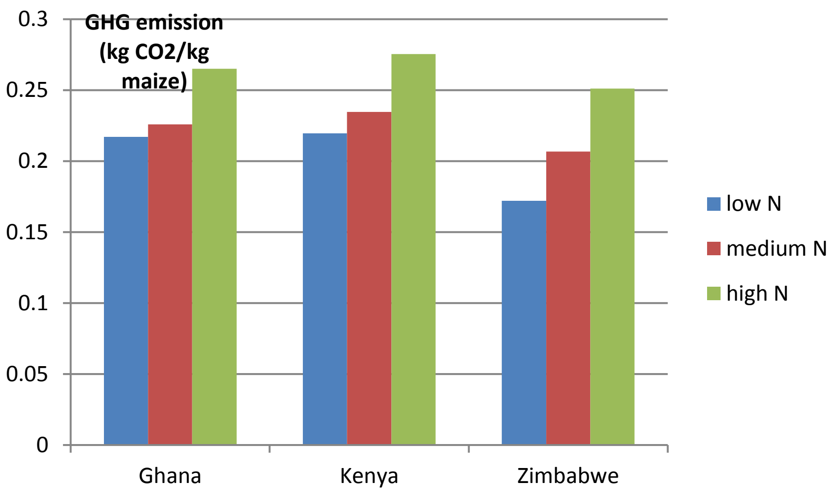


Figure 4.3 Greenhouse gas emissions at three levels of N input (low N – depending on location; medium N - 75 kg N ha^{-1}; and high N- 150 kg N ha^{-1}) in three case study areas.

4.3 Cash crops and income effects

In the previous section 4.2 we analysed the possibilities of farm households to produce maize for a growing urban market in relation to crop intensification, i.e. the use of N fertilizers to increase crop yields and thus a maize surplus that can be sold. In this section we look at the effects of production diversification towards growing a cash crop (soy bean), and the possibilities to enter more remunerative market segments.

The approach is similar as in the previous section but with the difference that farmers produce an amount of maize up to the (energy) needs of their family. Subsequently, any land surplus is used to grow soy bean, which is sold at the market. Similar to the previous section we show the results of one year for each case study area, the same year as used in section 4.2.

In the current situation with low maize and soy bean yields daily income levels are low, i.e. 70% of the households in Ghana, 99% in Kenya and 90% in Zimbabwe earn less than 1.25 USD capita^{-1}, the international poverty benchmark (Fig. 4.4). Absolute income levels of households differ considerably across the cases: the household with the highest income in Ghana earns almost 25 USD capita^{-1}, in Kenya it is less than 2 USD capita^{-1} while in Zimbabwe it is less than 3 USD capita^{-1}. Again it is emphasised that the shown data refer to a year with the highest maize yields in the period 1991-2010 and, therefore, in the other years income levels are lower because more land is needed for growing maize to satisfy energy requirements of the household.

Intensification affects crop income of farm household in two ways: First, higher maize yields imply that less land is required for achieving food self-sufficiency of households, hence more land is available for growing soy bean. Second, increased soy bean yields give higher financial returns from the surplus land cultivated with soy bean. However, because the effect of N fertilization on maize yields and P fertilizers and inoculum on soy yields are site-specific the outcome of the household income is non-linear and not the same for each case study area.

Intensification indeed results in improvements in crop income (Fig. 4.4), but only to a limited extent. In Ghana still 40% of the households remain living below the poverty line of 1.25 USD ha^{-1}, in Kenya this is even 90% of the households and in Zimbabwe about 50%. Furthermore, intensification of maize production and increase of income is associated with an increase in GHG emissions as shown in Fig. 4.3.

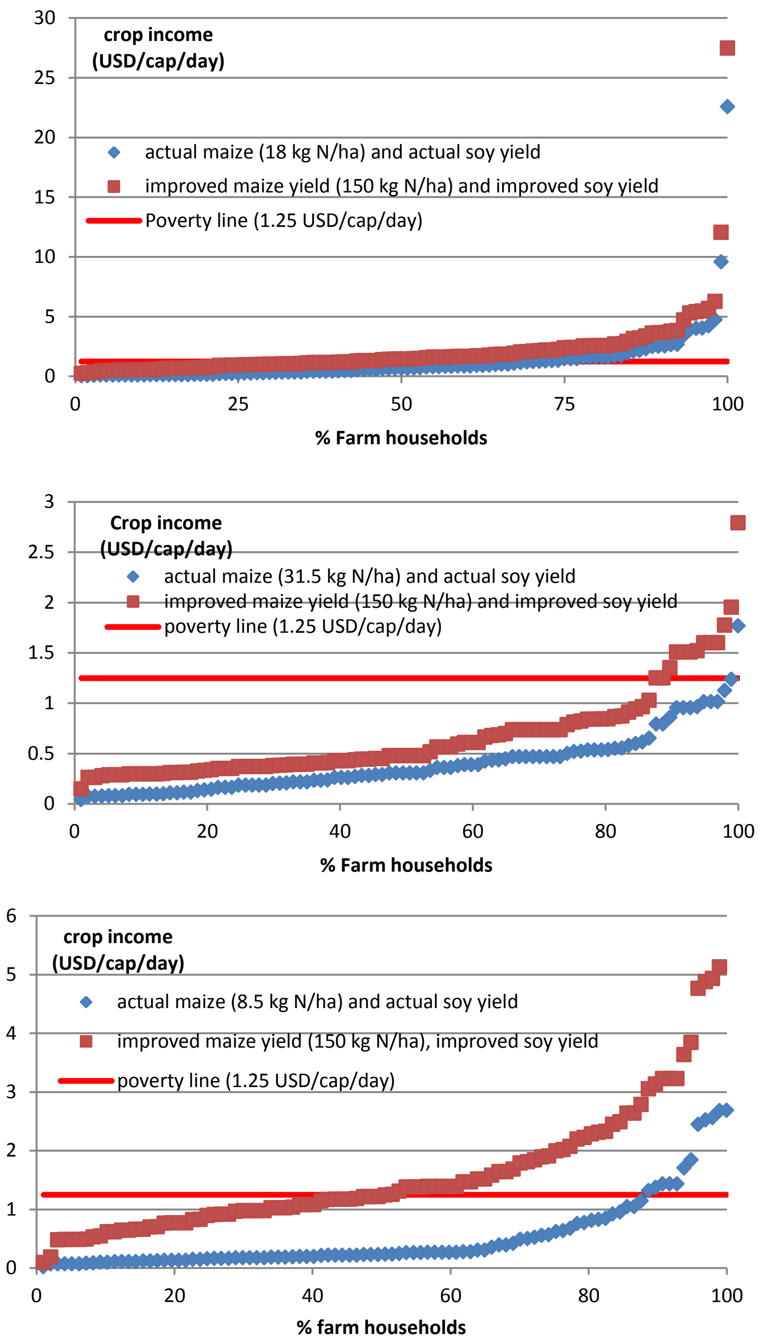


Figure 4.4 *Crop income of farm households associated with the production of maize for self-sufficiency and soy bean as cash crop in the three case study areas, top figure =Ghana; centre=Kenya; bottom=Zimbabwe. Note the different Y-axis.*

4.4 Effects of climate change on crop yields

Prospects for agriculture will be affected by climate change. In this section we show the results of simulated maize yields under expected climate conditions prevailing in 2035. See Figure 3.1 for the changed climate conditions during the growing season in the three case study areas.

The effect of climate change on maize yields is shown using an N input level 75 kg N ha^{-1} across the three case study areas. We show (i) yields under current climate conditions as benchmark, (ii) yields simulated using future climate, and (iii) yields under future climate but using a different maize variety which makes optimal use of the extended growing period (thanks to higher temperatures). For ease of comparison all simulated yield data are plotted against the period 1991-2010, including the yields simulated using future climate data. Latter simulated yields for this period are based on higher temperature and changed rainfall conditions as described in Chapter 3.

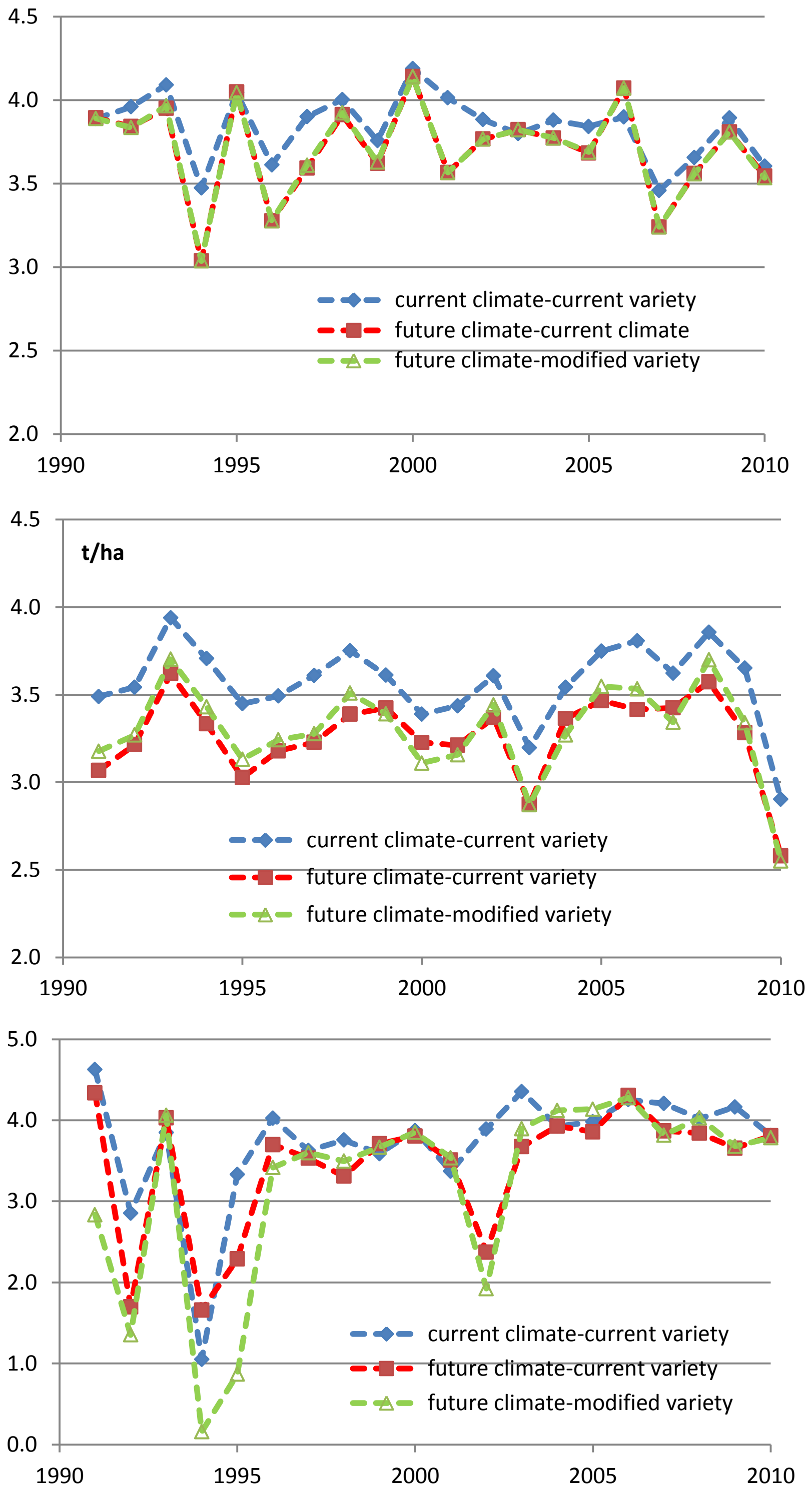


Figure 4.5 *Simulations of maize (75 kg N ha^{-1}) with current climate and current maize variety, future climate and current variety and future climate and modified variety for Ghana (top), Kenya (centre) and Zimbabwe (bottom). See text for explanation.*

Simulated yields under future climate conditions in all three case study areas follow the year-to-year variation in yields under current climate conditions because the Delta method for temperature and rainfall has been used (Fig.

4.5). Existing variation in crop yields is therefore either amplified or reduced. In general, simulated yields of current varieties under future climate conditions are lower because of higher temperatures, which shorten the crop growth periods (-12, -19 and -37 days for Ghana, Kenya and Zimbabwe, respectively). Using modified varieties compensates for this reduction in Kenya (+ 18 days) and Zimbabwe (+24 days), but not in Ghana. In Ghana current climate is relatively hot (average day temperature of circa 28 °C during the maize growth period) and it was assumed that the maize variety adapted to that current climate could not be modified for the higher temperatures of future climate expected in Ghana. In Zimbabwe the modified variety has still 13 growing days less than under current climate due to lower water availability which also affects the length of the growing period. This location has the largest yield variation (both under current and future climate conditions) and faces the most severe drought stress (expressed as ratio between rain fed and irrigated yield levels), which is aggravated by climate change. In Zimbabwe the modified variety is not producing better due to an increase in drought events during the maize growing period. If these events occur during flowering seed set may be hampered causing lower yields. In Kenya the water availability is close to the crop requirement (especially under future climate with >15% increase in rainfall relative to current climate, see Fig. 3.1) but the longer duration of the modified variety does not pay out at an input level of 75 kg N ha^{-1}. This is related to the interaction of water availability and nitrogen application affecting maize yields. In general rain fed potential levels (without N stress) tend to have higher differences both between years and between scenarios (data not shown), but with lower N input levels as used in the presented in Fig. 4.5 differences are dampened. Moreover, higher precipitation may reduce water stress (if water stress occurred) but also increases N losses from the soil which reduces the yield at given N application levels.

Based on these results one may conclude that in cases where water availability is low (e.g. Zimbabwe), modified varieties in this study, i.e. varieties with higher thermal time requirements than current varieties, may not provide an improvement and increased drought tolerance should also be part of these future genotypes. In cases where water is less limiting production (e.g. Kenya) varieties with higher thermal time requirements may produce marginally or significantly better than current varieties under future climate conditions due to the interaction with the N input level and change in losses of applied N linked to precipitation.

Obviously, household crop income as shown in Figure 4.4 will decrease under climate change as maize yields are expected to decline (Fig. 4.5). Especially in Kenya maize yields are each year structurally lower under changed climate conditions compared to current climate conditions.

4.5 Minimum land holdings to escape from poverty

The analysis in section 4.3 showed that crop income of small farm households is often much less than the poverty bench mark of 1.25 USD day^{-1} $capita^{-1}$. In this section we explore the minimum land holding of farm households to reach this bench mark under current climate conditions. We do not account for possible constraints that farm households face such as labour availability, credit supply to buy inputs, etc. to expand land holding. This simple analysis is only to illustrate the minimum land holding size to generate a crop income that equals the poverty benchmark of 1.25 USD day^{-1} cap^{-1}.

Figure 4.6 shows the minimum land holding requirements of average farm households in the three case study areas to earn at least 1.25 USD day^{-1} cap^{-1} in the period 1991-2010 based on current low N input levels. See Table 2.1 for the average farm household characteristics. Simulated maize yields differed across years thus affecting the minimum land holding requirements in each year. However, differences in these minimum land holding requirements are relatively small with the exception of Zimbabwe in 1994 when there was a crop failure (0.13 t ha^{-1}). In general, land holdings of approximately 3-3.5 ha will be sufficient to earn 1.25 USD day^{-1} cap^{-1}. In Kenya the minimum land holding requirements are a bit smaller than in Ghana and Zimbabwe because of two growing seasons. Yet, the minimum land holding requirements of 3-3.5 ha is much larger than the average land holding size in Kenya and Zimbabwe, which are 0.6 ha and 1.6 ha, respectively (Table 2.1). In Ghana, average land holdings are currently 3.1 ha (Table 2.1). Hence, current land holdings in Ghana are close to a size that a minimum crop income of 1.25 USD cap^{-1} day^{-1} can be earned.

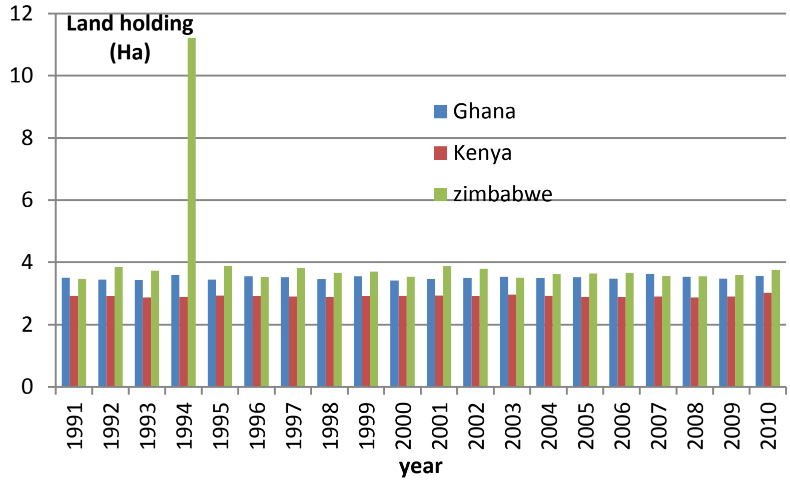


Figure 4.6 Minimum land requirements of average farm households in Ghana, Kenya and Zimbabwe needed to earn 1.25 USD day^{-1} cap^{-1} under current production conditions in the period 1991-2010.

Figure 4.7 shows the same analysis but for a higher N-input to maize (75 kg N ha^{-1}) and improved soy bean yields (20 kg P ha^{-1}). The effect is twofold: less land for maize is needed to satisfy household energy demands and higher income associated with soy bean production because of improved soy bean yields.

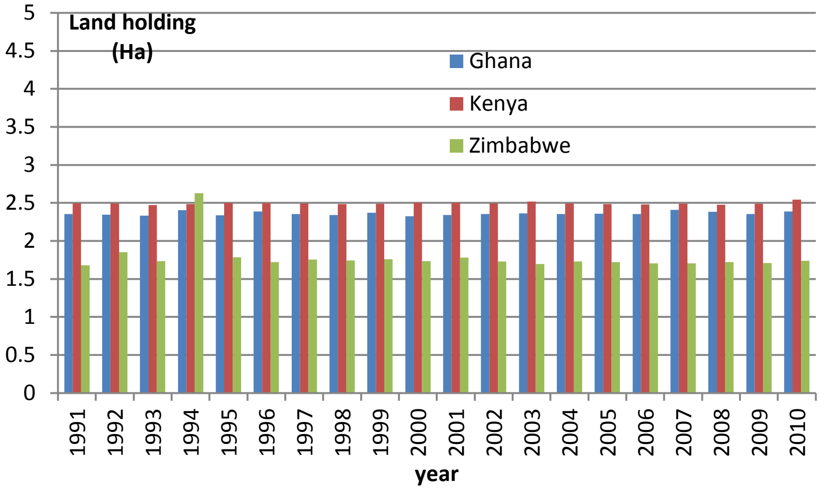


Figure 4.7 Minimum land requirements of average farm households in each year in Ghana, Kenya and Zimbabwe needed to earn 1.25 USD day^{-1} cap^{-1} under improved production conditions (75 kg N ha^{-1} in maize, 20 kg P ha^{-1} in soy bean).

In general, the minimum required land holding size decreases from 3-3.5 ha in the low N production situation (in Fig. 4.6) to 1.8 to 2.5 ha with higher N and P inputs (Fig. 4.7). In latter situation, the land holding size of farm households in Zimbabwe is smallest mainly because of the much higher soy bean yields compared to Kenya (nearly 1 t ha^{-1} higher) and Ghana (0.7 t ha^{-1} higher). Average maize yields across the case study areas and years at 75 kg N ha^{-1} do not differ much and vary between 3.6 t ha^{-1} (in Kenya), 3.7 t ha^{-1} (Zimbabwe) and 3.8 t ha^{-1} (Ghana). The extreme large land holding size in 1994 for the Zimbabwe case in the low N product situation (Fig. 4.6) disappears under improved input conditions as the simulated maize yield increased from 0.13 t ha^{-1} in the low N situation to 1 t ha^{-1}. However, the larger land holding size in 1994 needed for a crop income of 1.25 USD capita^{-1} day^{-1} is still visible in Fig. 4.7 as the maize yield of 1 t ha^{-1} is still far below the average simulated maize yield of 3.7 t ha^{-1} over the period 1991-2010. The observed variation in maize yields across years (Fig. 4.5) has only a limited effect on crop income as the maize income is less than 25% of the 1.25 USD capita^{-1} day^{-1}. The majority of the income is generated by the soy bean for which we used a constant average yield level across the various years. Both the small share of maize in crop income and the constant soy bean yield dampen the effects on the minimum land holding size required for gaining 1.25 USD capita^{-1} ha^{-1}.

At an input level of 75 kg N ha^{-1} the average minimum land requirements for farm households is still larger than the current average land holdings in Kenya and Zimbabwe. For Ghana these average minimum land requirements (to earn 1.25 USD day^{-1} capita^{-1}) are smaller than the current average land holding sizes suggesting that an average farm household can earn more than 1.25 USD day^{-1} capita^{-1}. However, actually realised maize yields by farmers will vary more than the simulated yields in this study, because aspects of pests and diseases have not been taken into account and these are expected to reduce yields but not at the same level in each year.

4.6 Food security at regional level

In this section the question is how much persons can be fed by the household sample in each case study area in addition to the food needs of the household members. This analysis links to the issue addressed in section 4.2, i.e. to what extent farm households in the case study areas are prepared to feed a growing non-farming population. The analysis differs from the one presented in section 4.2 that looked at the contribution of individual households to this goal, while here we look at the aggregated production of the household sample in each case study area and take into account the effect of climate change on maize productivity.

We assume that the households in the case study areas only grow maize, and we look at the amount of maize (in terms of kcal) available beyond the food needs (2,500 Kcal per capita per day) of all household members in each area. In the Ghana case the number of household members is 532, in Kenya it is 409 and in Zimbabwe it is 370. Figure 4.8 shows the number of persons that can be fed in addition to these household members under current climate conditions with low N input and consequently low maize yields, current climate and higher yields as a consequence of 75 kg N ha^{-1} and future climate conditions and an N input of 75 kg ha^{-1}.

Figure 4.8 shows that in Ghana most persons can be fed by the household sample because of the largest average farm holding size. In the current low input situation the food requirements of about 600 extra persons can be met in Ghana, in Kenya less than 200 persons, while in Zimbabwe the household sample is food deficient, i.e. additional food is required to feed the household sample. This poor food situation in Zimbabwe is consistent with the analysis in section 4.2 that showed that 60% of the households in Zimbabwe were food insecure during the most favourable production year 1991. Average current maize yield (period 1991-2010) in Zimbabwe was 0.63 t ha^{-1} and considerable lower than for Kenya (1.63 t ha^{-1}) and Ghana (1.14 t ha^{-1}). Intensification through higher N inputs results in remarkable improvements, in Ghana more than 3,000 persons can be fed, in Kenya more than 800 and in Zimbabwe on average 1400 persons, which is related to the largest yield increase at 75 kg N ha^{-1}. Under climate change conditions in combination with 75 kg N ha^{-1} the situation deteriorates slightly, on average 10% less persons can be fed in each case study area.

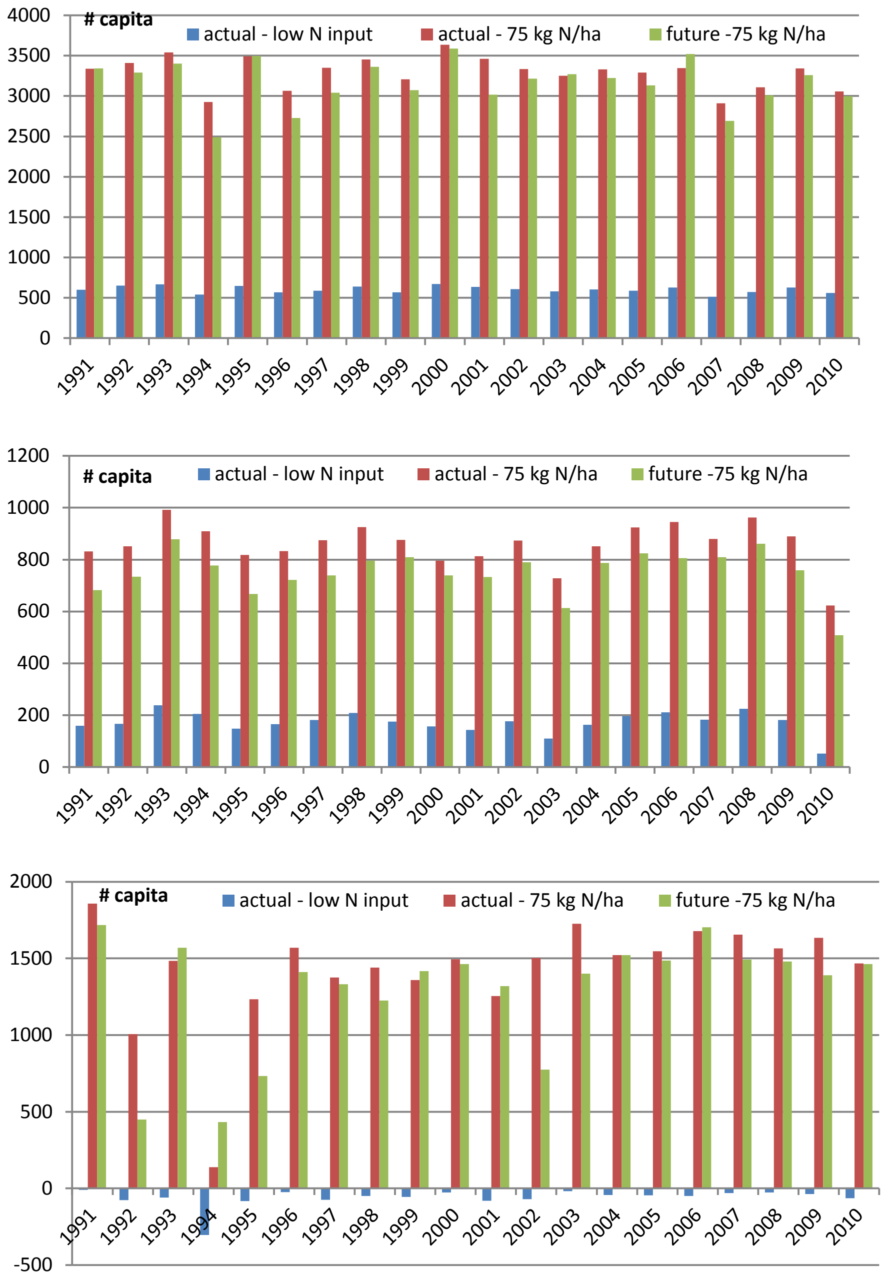


Figure 4.8 Number of persons that can be fed by the sampled households in each case study area in each year at different levels of N input, Ghana (top), Kenya (centre) and Zimbabwe (bottom).

5. Conclusions

This study contributes to the current debate on climate smart agriculture and development in Africa, specifically in relation to farm size, food security and intensification in rain fed farming areas (Masters et al., 2013; Harris and Orr, 2014; Jayne and Milu Muyanga, 2014; Jayne et al., 2014). Although the different analyses are rough, because of a combination of incomplete knowledge and limited data sets, the results places the prevailing development discussions in the context of CSA: Provides intensification a way out of poverty and contributes intensification to food security under climate change? How affects climate change crop yields and household income? Conflicts intensification with climate mitigation goals? These are some of the questions addressed for diverging case study areas in this study.

Seven issues stand out from the analyses:

1. Many of the analysed households are currently food insufficient, ranging from 25% in Ghana, 50% in Kenya to 70% in Zimbabwe. To improve the food self-sufficiency situation maize yields of some households in Kenya need to increase to 8 t ha^{-1}, while in Zimbabwe and Ghana yield levels of 3 and 4 t ha^{-1}, respectively are sufficient for most households to become food self-sufficient. For Zimbabwe and Ghana an increase of fertilizer N input to 75 kg N ha^{-1} is generally sufficient to reach the required yield levels, while in Kenya still 20% of the households remain food deficit at this input level. (section 4.1)
2. Obviously, under the sketched conditions, farm households in the case study areas are not able to feed a large number of people beyond own household food needs under current conditions. Even under the most favourable weather conditions between 20% (Ghana) and 60% (Zimbabwe) of the households is food deficit. Instead of producing food for the non-farming population they depend on food produced by other farms. However, with increasing N input levels of 150 kg N ha^{-1} even in Zimbabwe about 40% of the households can feed 10 persons (or more) per household capita. (section 4.2)
3. Intensification, i.e. more N input per hectare to increase crop yields, is associated with a 10-30% increase in GHG emissions expressed per unit of produced maize. Increased GHG emissions relate to the production and application of N fertilizers, N volatilization and N contained in crop residues. This means that intensification efforts to improve food self-sufficiency and income of poor households conflict with mitigation goals. (section 4.2)
4. Intensification of maize and soy bean production through higher nutrient inputs improves crop income of households, but only to a limited extent: In Ghana 40% of the households remains living below the poverty benchmark of 1.25 USD $capita^{-1}$ day^{-1}, in Zimbabwe 50% and in Kenya even 90% (section 4.3). Obviously, crop intensification only is not a feasible option for a large number of households in SSA to escape from poverty. (section 4.3)
5. In general, climate change reduces maize yields because of higher temperatures, which shorten crop growth periods with 12, 19 and 37 days in Ghana, Kenya and Zimbabwe, respectively. Annual variation in yields follows largely the variation under current climate conditions but this is an artefact of the used Delta method for temperature and rainfall. The simulation results also indicate at complex water-N interactions in the different case study areas, which need further further study to better understand and explanation. Obviously, with lower maize yields, household crop income will decrease under changing climate conditions. (section 4.4).
6. At current production levels minimum land holding sizes to achieve a crop income of 1.25 USD $capita^{-1}$ day^{-1} are remarkably similar in the three case study areas, i.e. approximately 3-3.5 ha, which is considerably larger than the current land holdings in Kenya (0.6 ha) and Zimbabwe (1.6 ha). At an input of 75 kg N ha^{-1} in maize and improved soy bean production, minimum land holding sizes become smaller (2.5 ha) but are still larger than current land holdings in Kenya and Zimbabwe. (section 4.5)
7. Under current conditions the aggregated household production in the three case study areas is able to feed an additional 600 (Ghana) and 200 (Kenya) persons while the households in Zimbabwe were food deficit and need food produced by other farms to satisfy household food energy needs. Production intensification (75 kg N ha^{-1} in maize) increases considerably the number of persons than can be fed on average, i.e. from 800 in Kenya, 1400 in Zimbabwe to 3000 in Ghana. Under changed climate conditions and same intensification level these numbers are on average 10% lower underlining the challenge that is posed by climate change to feed growing populations in SSA.

The study illustrates how CSA research questions can be addressed using a number of different metrices and analytical approaches. No final conclusions with respect to the achievement of the three pillars of climate smart agriculture can be drawn, but the cases and applied methods show clearly some of the trade-offs and paradoxes at stake: First, intensification of crop production is needed to improve the food self-sufficiency status of farm households and to feed a growing non farming population but it is not sufficient for a large share of the farm households to improve their livelihoods. Second, intensification increases GHG emissions thus contributing to climate change, which is a major threat for reduced crop yields in the future. Third, crop varieties with greater thermal time requirements are not a panacea to shortened growing periods under changed clime conditions. Preparing cropping systems to future climate conditions likely requires the modification of several crop traits (e.g. also drought tolerance) and better understanding of interactions among genotypes, management and local environmental conditions.

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Appendix I.

Towards a metrics for CSA

CLIMATE-SMART Agriculture 2015 Global Science Conference March 16-18, 2015 Le Corum, Montpellier France

Towards a Metrics for CSA

Jan Verhagen, Huib Hengsdijk, Sjaak Conijn, Annemarie Groot, Nico Polman, Theun Vellinga, Eddy Moors

Wageningen UR

Montpellier

March 16-18, 2015

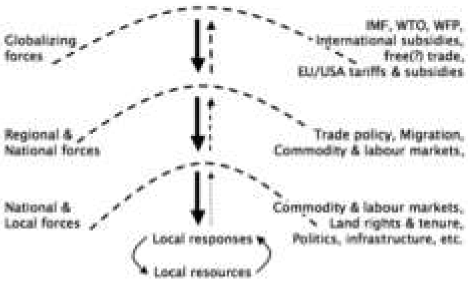
Why metrics?

To **inform decision-makers** about the **impacts** (including trade off and synergies) of climate smart agricultural activities and allow learning and evaluating.

Key criteria:

- Relevance for the decision maker
- Concise
- Quantifiable
- Link to or use existing monitoring systems
- Allowing monitoring of progress
- Easy to communicate
-

Nestedness of the decision makers



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Metrics framework objectives:

- insight in the effects of activities applied by the decision maker to reach their goals;
- insight in the connections and interdependencies between different decision makers;
- insight in the trade-offs between food productivity, climate resilience and GHG emissions;
- a basis for discussions with decision makers and stakeholders around trade-offs and thresholds.

Scales

Spatial scale	Jurisdiction scale	Main stakeholders
Global	Global	Governments
	National	Consumer
Macro(basin)	District	Weatherboard/ Retailer
Landscape	Community	Commodity processor
Farm/Household	Household level/farm	Farmer

Steps

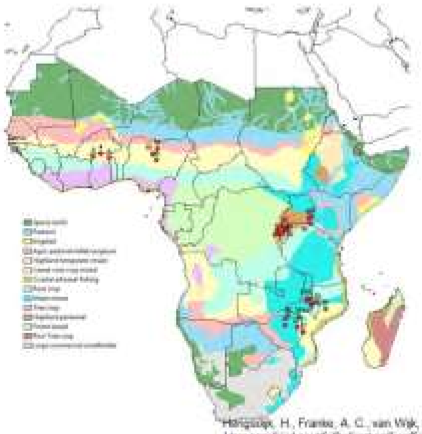
1. Identify the decision maker and understand the objectives and activities the decision maker;
2. Understand the context (social, financial, technical, natural, human) of the decision maker;
3. Map activities undertaken by the decision maker to reach the objectives
4. Understand the impacts of the activities (trade-offs and synergies)

Scales

Spatial scale	Jurisdiction scale	Main stakeholders
Global	Global	Governments
	National	Consumer
Macro(basin)	District	Weatherboard/ Retailer
Landscape	Community	Commodity processor
Farm/Household	Household livelihood	Farmer

CLIMATE-SMART Agriculture 2015

Context & Assets



CLIMATE-SMART Agriculture 2015

Hengsdijk, H., Franke, A. C., van Wijk, M. T., & Giller, K. E. (2014). *How small is beautiful?: food self-sufficiency and land gap analysis of smallholders in humid and semi-arid sub Saharan Africa.*

Context & Assets

	Ghana Northern region	Kenya Wamalama	Zimbabwe Makoni
Sample size (#FHH)	104	97	98
Number of growing seasons	1	2	1
Average annual rainfall 1981-2010 (mm)	984	1794	863
Agro-ecological zone	Tropical warm/subhumid	Tropical cool, humid	Tropical warm/semi-arid
Population density (per km2)	61-70	1200	30
Average land holding size (ha)	3.1	0.6	1.6
Average FHH size (capita)	5.1	4.2	3.8
Land availability (ha/cap)	0.61	0.14	0.42
Tropical Livestock Units per FHH (#)	4.4	1.4	1.9
% female household heads	0	47	40
% FHH with income > 75% from farming	85	58	47
Number of cultivated crop types	4.4	3.5	2.9

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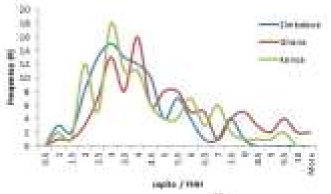
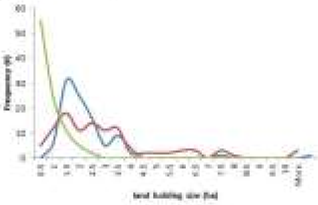
Hengsdijk, H., Franke, A. C., van Wijk, M. T., & Giller, K. E. (2014). *How small is beautiful?: food self-sufficiency and land gap analysis of smallholders in humid and semi-arid sub Saharan Africa*

Variation in FHHs





Objectives: Farm Household

1. food self-sufficiency
2. income above the poverty level;

Objectives CSA

1. Food security
2. Resilience
3. Low emission pathway

Methods

- Food self-sufficiency:
  - Crop model to calculate: land requirements to satisfy own household food requirements with maize: 'land gap' for those households that cannot produce sufficient food, or a 'land surplus' for those households that are able to produce a surplus. The surplus can be used for a cash crop (soy).
- Income:
  - The net revenue is defined as the difference between the production times the price and the costs of production. For maize the costs consists of the costs for N fertilizer (based on long-term monthly average IFDC prices for urea) and for soya bean the costs consists of seed and P fertilizers (with or without inoculum). Production costs for soya bean have been collected in the N2AFRICA project.
- GHG emissions
  - Associated with the different production levels we estimate greenhouse gas (GHG) emissions, which in our case relate to external N fertilizer input (100% urea) and N contained in crop residues, which remain in the field after crop harvest. We use default methods (Tier one, IPCC)

Climate baseline: 2000; future 2035.

Looked at:

1. Food self-sufficiency analysis: At what maize yields small farm households become self-sufficient in food
2. Income effects of growing cash crops: To what extent small farm households in the case study areas can participate in market-led developments and what are the income effects?
3. Effects of climate change on maize yields: how do future climate conditions affect maize yields and to what extent can climate smart variety choices alleviate yield reductions under future climate conditions?

And:

1. Food supply analysis: To what extent small farm households in the three case study areas are able to feed a rapidly growing urban population in sub Saharan Africa?
2. Effects of climate change on household income.
3. GHG emissions related to N application
4. Minimum household land holding to allow gaining more than poverty benchmark

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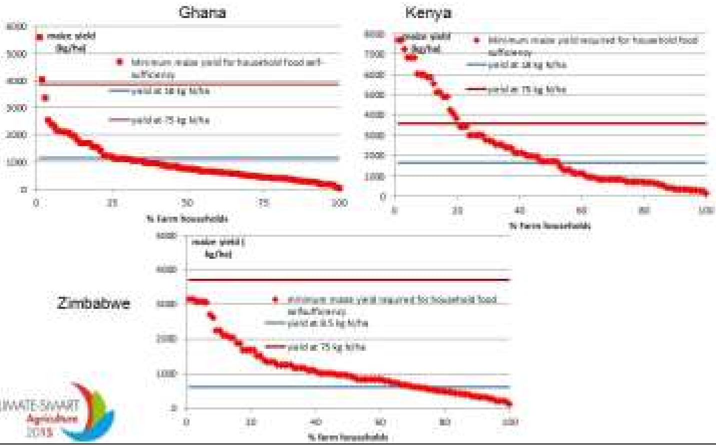
Minimum required maize yield



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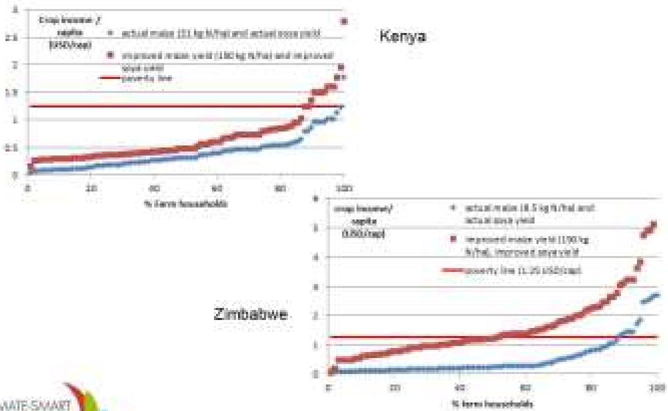
Income effects



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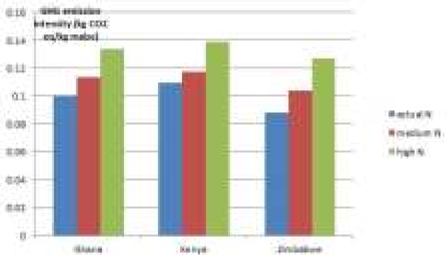
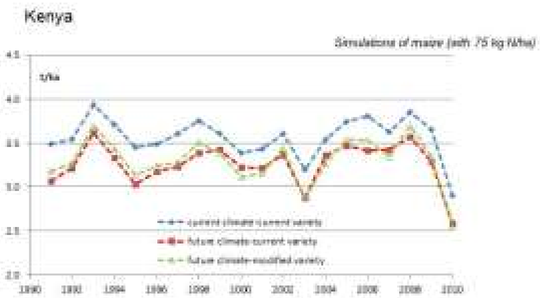
GHGi



Impact of CC

- Negative in all regions: outcomes are worse than for baseline period (mainly related to increased temperature): will have a negative affect on all other indicators



Final remarks

- Indicators based on relevance for stakeholder.
- Need to work at different scales esp markets and water (not shown in this presentation)
- Models to quantify effects are available
- Resilience is now linked to variability
- No clear smart picture emerges -> development priorities may link to adaptation (N application & farm size), GHG emissions/GHGi increase.