Evidence-based opportunities for out-scaling climate-smart agriculture in East Africa

Working Paper No. 172

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Christine Lamanna, Nictor Namoi, Anthony Kimaro, Mathew Mpanda
Anthony Egeru, Clement Okia, Julian Ramirez-Villegas,Caroline Mwongera,
Edidah Ampaire, Piet van Asten, Leigh Winowiecki,
Peter Läderach, Todd S. Rosenstock

RESEARCH PROGRAM ON
Climate Change,
Agriculture and
Food Security

CGIAR CCAFS World Agroforestry Centre

Working Paper

Evidence-based opportunities for out-scaling climate-smart agriculture in East Africa

Working Paper No. 172

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Christine Lamanna
Nictor Namoi
Anthony Kimaro
Mathew Mpanda
Anthony Egeru
Clement Okia
Julian Ramirez-Villegas
Caroline Mwongera
Edidah Ampaire
Piet van Asten
Leigh Winowiecki
Peter Läderach
Todd S. Rosenstock

Correct citation:
Lamanna, C, Namoi N, Kimaro A, Mpanda M, Egeru A, Okia C, Ramirez-Villegas J, Mwongera C, Ampaire E, van Asten P, Winowiecki L, Läderach P, Rosenstock TS. 2016. Evidence-based opportunities for out-scaling climate-smart agriculture in East Africa. CCAFS Working Paper no. 172. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org

Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic partnership of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT). The Program is carried out with funding by CGIAR Fund Donors, the Danish International Development Agency (DANIDA), Australian Government (ACIAR), Irish Aid, Environment Canada, Ministry of Foreign Affairs for the Netherlands, Swiss Agency for Development and Cooperation (SDC), Instituto de Investigação Científica Tropical (IICT), UK Aid, Government of Russia, the European Union (EU), New Zealand Ministry of Foreign Affairs and Trade, with technical support from the International Fund for Agricultural Development (IFAD).

Contact:
CCAFS Coordinating Unit - Faculty of Science, Department of Plant and Environmental Sciences, University of Copenhagen, Rolighedsvej 21, DK-1958 Frederiksberg C, Denmark. Tel: +45 35331046; Email: ccafs@cgiar.org

Abstract

Climate-smart agriculture (CSA) is being widely promoted as a solution for food insecurity and climate change adaptation in food systems of sub-Saharan Africa, while simultaneously reducing the rate of greenhouse gas emissions. Governments throughout Africa are writing policies and programs to promote CSA practices despite uncertainty about the ability for practices to meet the triple CSA objectives of CSA. We conducted a systematic review of 175 peer-reviewed and grey literature studies, to gauge the impact of over seventy potential CSA practices on CSA outcomes in Tanzania and Uganda. Using a total of 6,342 observations, we found that practice impacts were highly context (i.e. farming system and location) specific. Nevertheless, practice effect across CSA outcomes generally agreed in direction. While our results suggest that CSA is indeed possible, lack of mitigation data precludes a more conclusive statement. Furthermore, the inclusion of potential adoption rates changes the potential of CSA practices to achieve benefits at scale. Given the uncertainty and variable impacts of practices across regions and outcomes, it is critical for decision makers to prioritize practices based on their desired outcomes and local context.

Keywords

Climate-smart agriculture, Tanzania, Uganda, adoption, resilience, maize, decision making

About the authors

Christine Lamanna[1*], Nictor Namoi[1], Anthony A. Kimaro[2], Mathew Mpanda[2], Anthony Egeru[3], Clement Okia[4], Julian Ramirez-Villegas[5,6,7], Caroline Mwongera[8], Edidah Ampaire[9], Piet van Asten[9], Leigh Winowiecki[8,#a], Peter Läderach[5], and Todd S. Rosenstock[1,7]

[1] World Agroforestry Centre (ICRAF), Nairobi, Kenya

[2] World Agroforestry Centre (ICRAF), Dar es Salaam, Tanzania

[3] Department of Environmental Management, School of Forestry, Environment and Geographical Sciences, Makerere University, PO Box 7062, Kampala, Uganda.

[4] World Agroforestry Centre (ICRAF), Kampala, Uganda

[5] International Center for Tropical Agriculture (CIAT), Cali, Colombia

[6] School of Earth and Environment, University of Leeds, Leeds, UK

[7] CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS)

[8] International Center for Tropical Agriculture (CIAT), Nairobi, Kenya

[9] International Institute of Tropical Agriculture (IITA), Kampala, Uganda

[#a] Current Address: World Agroforestry Centre (ICRAF), Nairobi, Kenya

[*] Corresponding author: Christine Lamanna, PO Box 30677-00100, United Nations Avenue, Nairobi, Kenya, c.lamanna@cgiar.org, phone: +254 20 722 4064

Acknowledgements

We thank A. Poultouchidou, A. Akinyale, P. Bell, D. Grunzel, M. Ravina, S. Rayess, and Z. Cheng for assisting with reference screening and data extraction. This work was carried out as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Data collection was supported by the 'Increasing Food Security and Farming System Resilience in East Africa through Wide-Scale Adoption of Climate-Smart Agricultural Practices' project, funded with support from the International Fund for Agriculture Development Grant number 2000000176. C. Lamanna and T. Rosenstock were supported by CCAFS Flagship Project 'Partnerships for Scaling Climate-Smart Agriculture'. JR-V was supported by the Climate Smart Agriculture Flagship of CCAFS.

Contents

Introduction

Currently, food production in much of Africa falls short of both need and potential productivity [1-3]. Projected future increases in growing season temperature, the unpredictability of precipitation patterns, and the frequency of extreme events threatens production even further [4,5]. Yields of maize and beans, the most widely planted crops in SSA, may decrease by 25 to 50 % by 2050 [5,6]. Locally, the projected rates of productivity decline may be even higher. For example, yields of beans are projected to decline in Tanzania by up to 75 % by 2040 if no adaptation actions are taken [8]. Productivity of livestock is also likely to decline. Feed intake by cattle declines 2.5 % for every degree above 30 ºC, which will have cascading impacts on productivity of milk and meat. Given both persistent and widespread food insecurity in SSA and future risks to food production from climate change, new solutions are urgently needed to improve the productivity and resilience of smallholder farmers in the region.

Climate-smart agriculture (CSA), agriculture and food systems that (1) enhance food security, (2) improve resilience to climate variability and change, and (3) mitigate greenhouse gas emissions where appropriate [9,10], may be a solution to the food and climate challenges facing sub-Saharan smallholder farmers. Many farm-level management practices have been identified as being climate-smart, from agroforestry to improved storage of grain postharvest. However, not all CSA practices deliver "triple-wins" in all locations. For instance, in sub-humid western Kenya, conservation tillage depressed maize yields by approximately 16% and decreased rainfall infiltration compared to conventional tillage [11], whereas in drier areas such as southern Zimbabwe, conservation tillage has increased maize yields, rainfall infiltration, and soil carbon [12]. Such conflicting results illustrate the main challenge for CSA planning: context specificity. That is, practices may produce the desired CSA benefits in one place but may have contrasting impacts in others. Therefore, decision-makers must carefully choose those agricultural management practices that have the highest likelihood to deliver the desired outcomes locally.

Recognizing the potential of CSA for agricultural development, political institutions and governments across sub-Saharan Africa are creating CSA-specific policies and programs. In 2015, Kenya, Uganda, Namibia, Botswana, and Tanzania drafted CSA Country Programmes that set national agendas on CSA [13]. At the same time, learning alliances are forming to operationalize the plans and move CSA into action [14]. However, programmes and policies have largely been based on a limited amount of data and evidence, because systematic evidence on the effectiveness of potential CSA practices across multiple CSA outcomes is lacking [15].

Here we conducted a systematic review and meta-analysis of agricultural management practices and technologies for two countries in East Africa, Uganda and Tanzania, to determine the evidence-base and identify opportunities for CSA planning in the region. We first compiled peer-reviewed scientific and grey literature on potential CSA practices. We included grey literature in the systematic review as it may contain a significant amount of evidence on the impact of agricultural practices on CSA outcomes, particularly in developing countries, and failure to include grey-literature in meta-analyses may bias results [16]. We then used the resulting data, along with probabilistic simulations, to identify evidence-based opportunities for out-scaling CSA, given various decision-maker contexts and priorities.

Results

Dataset

The systematic review resulted in a pool of 61 peer-reviewed studies in Tanzania, and 33 in Uganda, for a meta-analytical inclusion rate of approximately 10-13% in both countries. Screening of the located grey literature resulted in 56 studies included from Tanzania, and 25 from Uganda. The final dataset consisted of 6,342 observations of the impact of a practice on a CSA outcome relative to a control, split almost evenly between Tanzania and Uganda, and between peer-reviewed and grey literature. All CSA technologies and outcomes were organized into hierarchical classifications to allow for analysis at different levels of aggregation. For a list of technology and outcome classifications see Appendix I and [15].

Data gathered from Uganda covered 26 different practices from 25 and 33 studies in grey and peer-reviewed literature respectively. Grey literature contributed 66% of the data, but did not cover any practices that were not already covered in the peer-reviewed literature. The most studied practice was inorganic fertilizer application (35.4% of the observations). Other well-represented practices included organic fertilizers (9.5 %), crop rotation (3.4%), and green manure (3.4%). Millet was the crop with the most data available (26% of the observations), followed by maize (17.8%), the cash crop sesame (15.2%), and roots and tubers like cassava (11.5%). In total, 12 different agricultural products were covered in the database. While the geographic coverage of the studies was not limited to only one farming system or region of Uganda, there was little to no information available from the northeastern region, which is the most arid part of the country, dominated by pastoral and mixed crop/livestock systems (Figure 1).

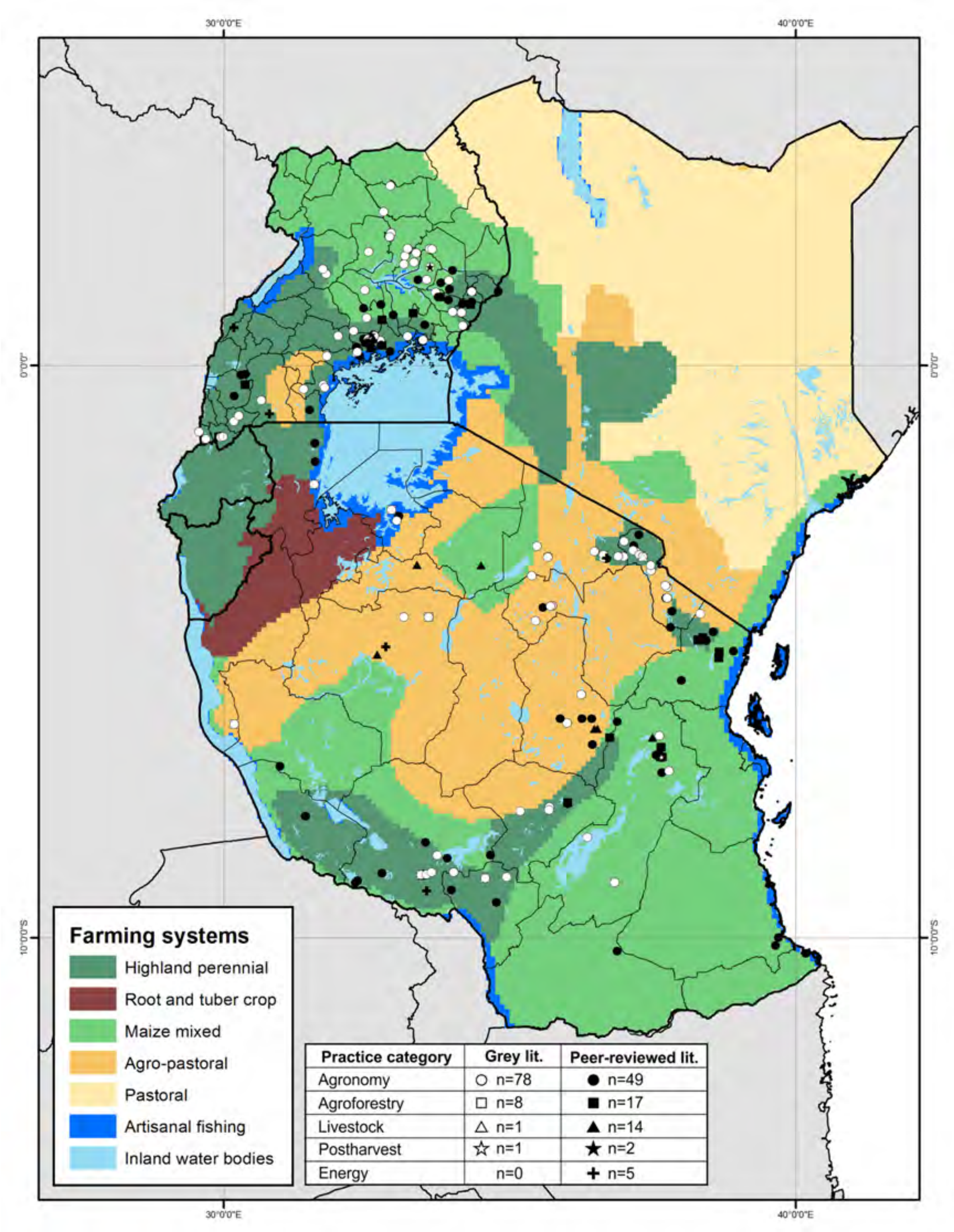

Figure 1: *Location of sites of studies included in the meta-analysis in Uganda (n=58) and Tanzania (n=117), overlaid on the farming systems of East Africa [17]. Peer-reviewed studies are shown with black markers, and grey literature with white markers, while marker shape indicates the theme of the practice studied.*

In Tanzania, a total of 29 practices were covered in the database, from 61 peer-reviewed and 56 grey literature sources. Grey literature contributed roughly one-third (37.6 %) of the observations in the dataset, and added information on six practices that were otherwise not covered in the peer-reviewed literature, namely, conservation agriculture, crop rotation, hybridization of livestock, postharvest storage technologies, use of agroforestry prunings as soil amendments, and system of rice intensification. Inorganic fertilizer research was best represented (33 % of the observations), followed by organic fertilizer (11.2 %), intercropped agroforestry (7.8%), and reduced tillage (6.7 %). By far the most studied crop was maize, representing 52.5 % of the data collected. Other well-represented crops included legumes (11 %), sorghum (6 %), and rice (5%). Geographically, all of the farming systems in Tanzania were represented in the dataset, except for the root and tuber system (Figure 1).

Effect Sizes

At the aggregate level, the effect of practices on CSA outcomes varies both within and between practices. Some practices, such as nutrient management (which includes inorganic and organic fertilizers) have clearly positive and geographically consistent impacts on productivity (effect size = 0.34 ± 0.07 in Tanzania, and 0.37 ± 0.04 in Uganda, Figure 2). Other practices, such as agroforestry, have more variable impacts on productivity both within and between countries (effect size = 0.28 ± 0.11 in Tanzania, and 0.09 ± 0.11 in Uganda). suggesting substantial context dependencies. In Tanzania, the practices with the largest mean effect size on productivity are postharvest improvements (0.45 ± 0.17), soil management (0.37 ± 0.04), and water management (0.37 ± 0.11). In Uganda, livestock diet management (1.15 ± 0.33), nutrient management (0.37 ± 0.04), and soil management (0.36 ± 0.06) have the largest effect on productivity.

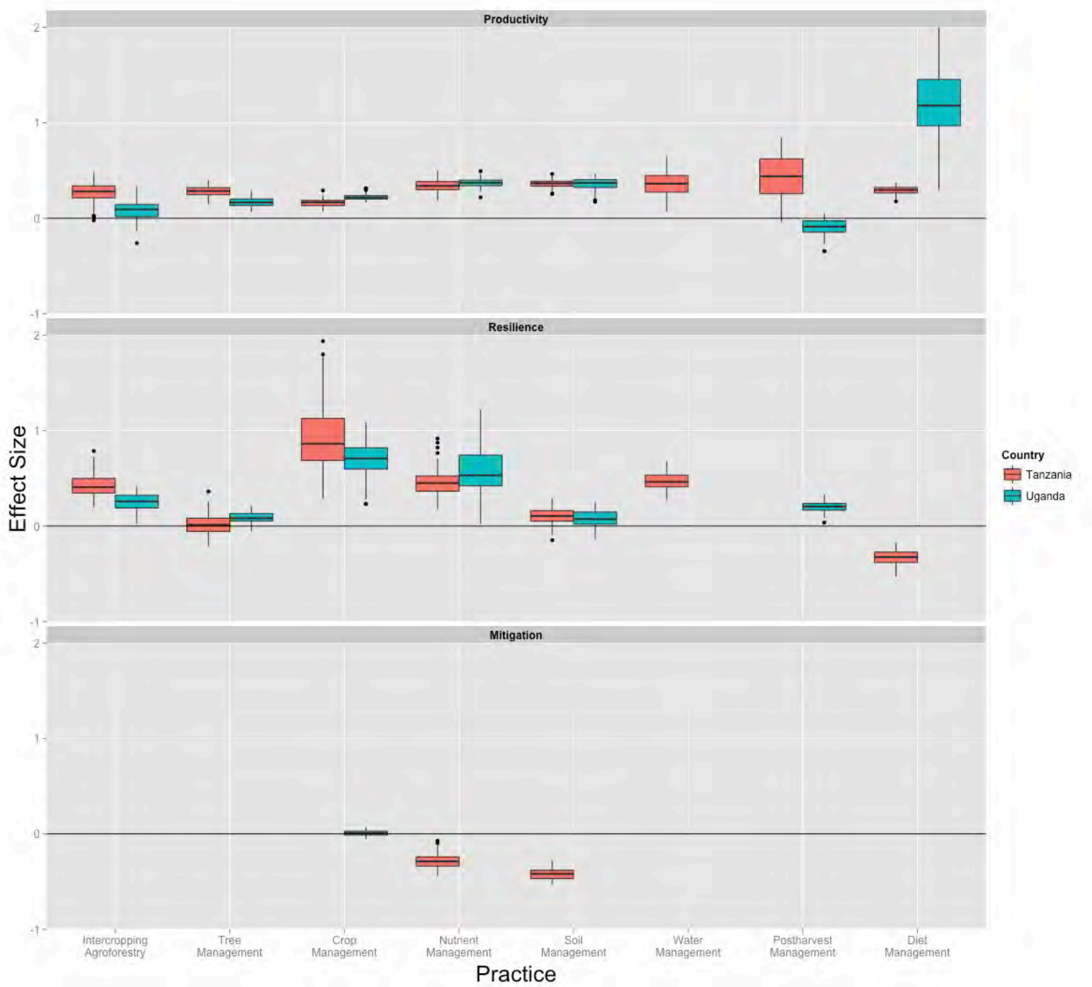

Figure 2: *Weighted mean effect size of aggregate climate-smart agricultural practices on productivity indicators (top panel), resilience indicators (middle panel), and mitigation indicators (bottom panel), in Tanzania (red) and Uganda (teal). Box plots represent the median and quartiles of the weighted mean effect size from 1000 samples from the database. An effect size of 1 is a 278% increase in the value of the indicator for the practice relative to the control.*

Practices also vary in effect on different CSA pillars (i.e. productivity, resilience, mitigation), at both aggregate and disaggregate levels. The practices that have the largest effect size in productivity do not necessarily have the largest effect size in other pillars. At the aggregate level, crop management has the largest mean impact on resilience in Uganda (0.68 ± 0.18), followed by nutrient management (0.58 ± 0.03), while in Tanzania, crop management (0.85 ± 0.31) and nutrient management (0.49 ± 0.13) have the largest positive impacts on resilience indicators (Figure 2). While very little mitigation data was available for CSA practices in

Tanzania and Uganda, the data again show variable impacts of CSA practices on mitigation indicators between practices and locations. When practices are disaggregated into specific technologies such as green manure or water harvesting, the variation in effect size between pillars and locations is still apparent (Appendix II).

The effect sizes of specific technologies on CSA pillars are not significantly different between the grey and peer-reviewed literature ($p = 0.86$, two tailed $t_{85}=-0.17$). When plotted against one another, the effect sizes do not diverge from a 1:1 correspondence between grey and peer-reviewed literature at low effect sizes (Figure 3). However, at the highest grey literature reported effect sizes (ES > 0.5), the grey literature effect sizes are larger than the peer-reviewed effect sizes for the same subpractice, country, and outcome combinations ($p \cong 0$, two tailed $t_{16} = -5.76$).

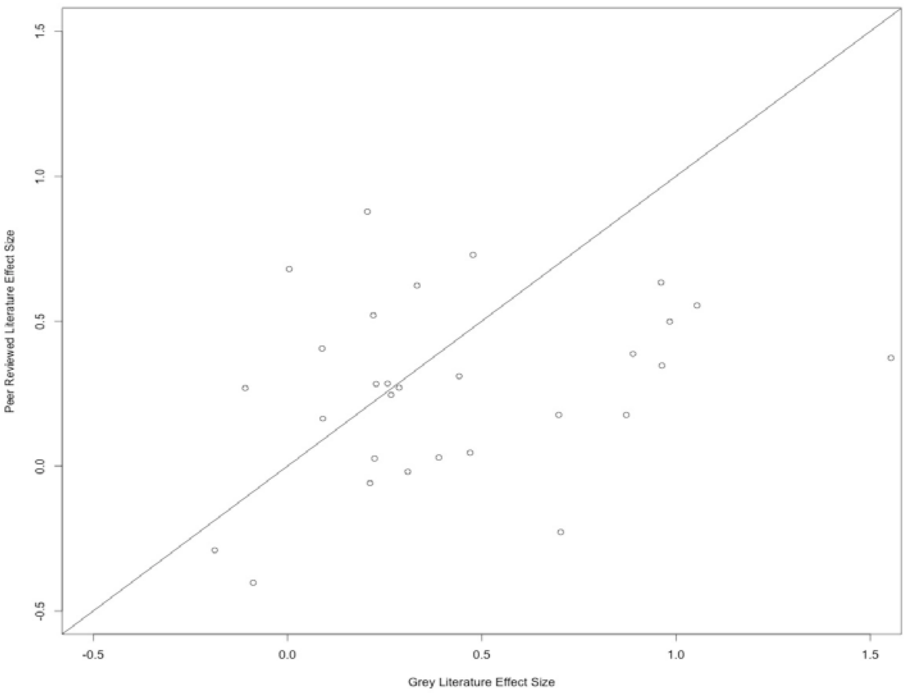

Figure 3: *Comparison of effect sizes from grey literature versus peer-reviewed literature for each CSA subpractice, CSA pillar, and country combination with data from both the peer-reviewed and grey literature. Line showed is the one-to-one line, where the effect size from peer-reviewed literature and grey literature are equal.*

Potential Yields under CSA

While practices differ in their effect on aggregated productivity and resilience outcomes, they also vary in their effect on the individual indicators of these outcomes (e.g. income, product yield, nutrient use efficiency, labour, soil carbon, etc. see Appendix III and IV). Furthermore, within one specific indicator such as product yield, practices vary in their suitability for different specific farming systems or agricultural products, and their potential adoption rates. Table 1 lists a major agricultural crop for smallholder farmers in each of Tanzania and Uganda, the percentage of smallholder households growing that crop, the mean yield per hectare and the total area of the crop under smallholder cultivation. While the mean effect of agroforestry intercropping on maize yield in Tanzania is to reduce yields (effect size = -0.13 ± 0.529), the largest mean increase in maize yield was seen with addition of organic fertilizers (0.63 ± 0.31) of all of the studied practices. Similarly, in Uganda, the biggest increase in yield of banana came from application of organic fertilizers (0.61 ± 0.16). However, these practices also vary in the uncertainty in the effect size, and in their likely adoption rates. When we account for these differences, the practice that produces the highest mean potential yield of maize in Tanzania is water harvesting via terraces, contours, ridges or bunds (1.57 t ha^{-1}), and mulching (6.53 t ha^{-1}) for banana in Uganda. Although the effect size for water harvesting in Tanzania is low (0.56) compared to some of the other CSA practices, its high adoption rates result in higher national-level change in maize yields. For a full analysis of all practice and crop combinations in Uganda and Tanzania see Appendix V.

Table 1. Potential yield of maize in Tanzania and bananas in Uganda under different climate-smart agricultural practices

Crop	% HHs[1]	Area[1] (10^6 ha)	Yield[1,2] (t ha^{-1})	Practice	Effect Size[3]	Adoption (%)[4]	Potential Yield (t ha^{-1})
				-Tanzania-			
Maize	87.5%	4.09	1.33 ± 0.28	Agroforestry	-0.13 ± 0.52 $_{(12,98)}$	13 ± 8%	1.35 ± 0.31
				Green Manure	0.28 ± 0.36 $_{(7,70)}$	7 ± 7%	1.39 ± 0.30
				Improved Varieties	0.18 ± 0.15 $_{(7,147)}$	13 ± 10%	1.37 ± 0.30
				Organic Fertilizer	0.63 ±0.31 $_{(11,126)}$	15 ± 13%	1.55 ± 0.41
				Reduced Tillage	0.47 ± 0.35 $_{(9,140)}$	24 ± 8%	1.54 ± 0.39
				Water Harvesting	0.56 ± 0.43 $_{(6,63)}$	20 ± 13%	1.57 ± 0.44
				-Uganda-			
Banana	39%	4.02	5.34 ± 1.12	Agroforestry	-0.06 ± 0.59	16 ± 10%	5.46 ± 1.31
				Inorganic Fertilizer	0.26 ± 0.25 $_{(5,81)}$	5 ± 4%	5.43 ± 1.18
				Mulching	0.47 ± 0.28 $_{(4,37)}$	29 ± 27%	6.53 ± 1.86
				Organic Fertilizer	0.61 ± 0.16 $_{(1,20)}$)	21 ± 17%	6.54 ± 1.60

[1]Sources: United Republic of Tanzania National Sample Census of Agriculture 2007/2008 and Uganda Census of Agriculture 2008/2009. Area is the sum of area planted under that crop in the long rains and short rains. % Smallholder households (%HHs) is a percentage of total households planting the crop in the long rains and short rains. [2]Yield the mean of yield per region weighted by area. [3] Numbers in brackets show the number of studies and number of data points behind each effect size. [4]Adoption figures are means of published adoption rates from studies described in Methods

The full probability distribution for smallholder maize yield shows that the practice most likely to double maize yields in Tanzania is the addition of organic fertilizers, followed by reduced tillage, and water harvesting techniques such as contours and bunds (Figure 4a, top panel). However, when differences in adoption rates are taken into account, water harvesting becomes the practice most likely to double maize yields (Figure 4a, bottom panel). Regardless of whether adoption rates were accounted for, crop rotation was the practice most likely to halve maize yields. Similarly in Uganda, while organic fertilizers are the practice most likely to double banana yields (Figure 4b, top panel), the higher adoption rate of mulching makes it the practice most likely to double yields when accounting for adoption (4b, bottom panel).

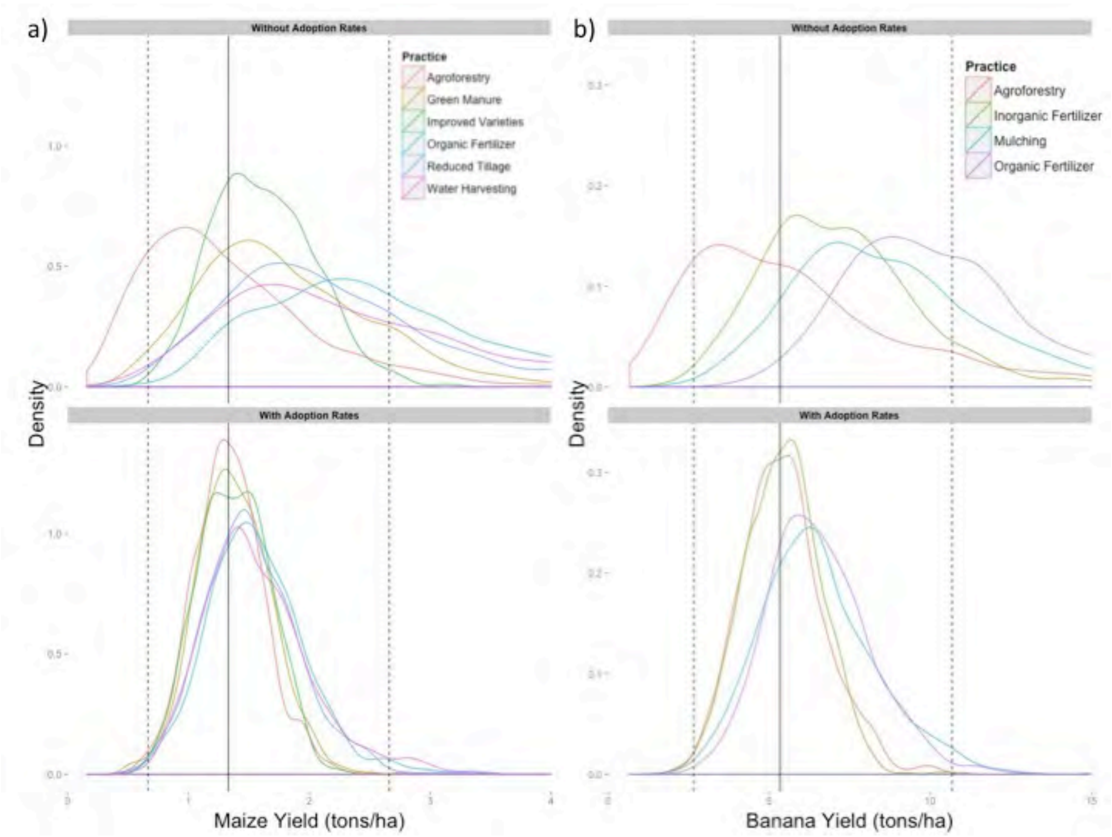

Figure 4: *Likelihood of various levels of (a) smallholder maize yield in Tanzania, and (b) smallholder banana yield in Uganda under different CSA practices assuming 100% adoption of the CSA practice (top panels) and using published adoption rates for each practice (bottom panels). The current mean yields of each crop are shown in solid vertical lines, and the dashed vertical lines show halving and doubling of current crop yields.*

Prioritization of CSA Practices

The ranking of practices based on effect size is highly sensitive to choice of outcomes or indicators in both Tanzania and Uganda, suggesting the choice of practices is dependent on how CSA is defined. Fig. 5 shows such a prioritization for the two countries, taking into account all resilience and productivity indicators. When only aggregated productivity indicators are considered (product yield, residue yield, income, etc.), improved fallows, organic fertilizers, and water harvesting are the 'best-bet' practices in Tanzania, while organic fertilizer, crop residue retention, and mulching are the highest ranked practices in Uganda (Figure 5). However, the ranking changes when only resilience indicators (soil quality, erosion, labour, nutrient use efficiency, biodiversity, etc.) are considered. Notably, a unique optimization of practices results from each particular weighting of productivity relative to resilience indicators. In spite of differences in top-ranked practices across the two CSA outcomes, however, it is possible to identify the most climate-smart practices; that is, practices that are ranged high for both CSA outcomes.

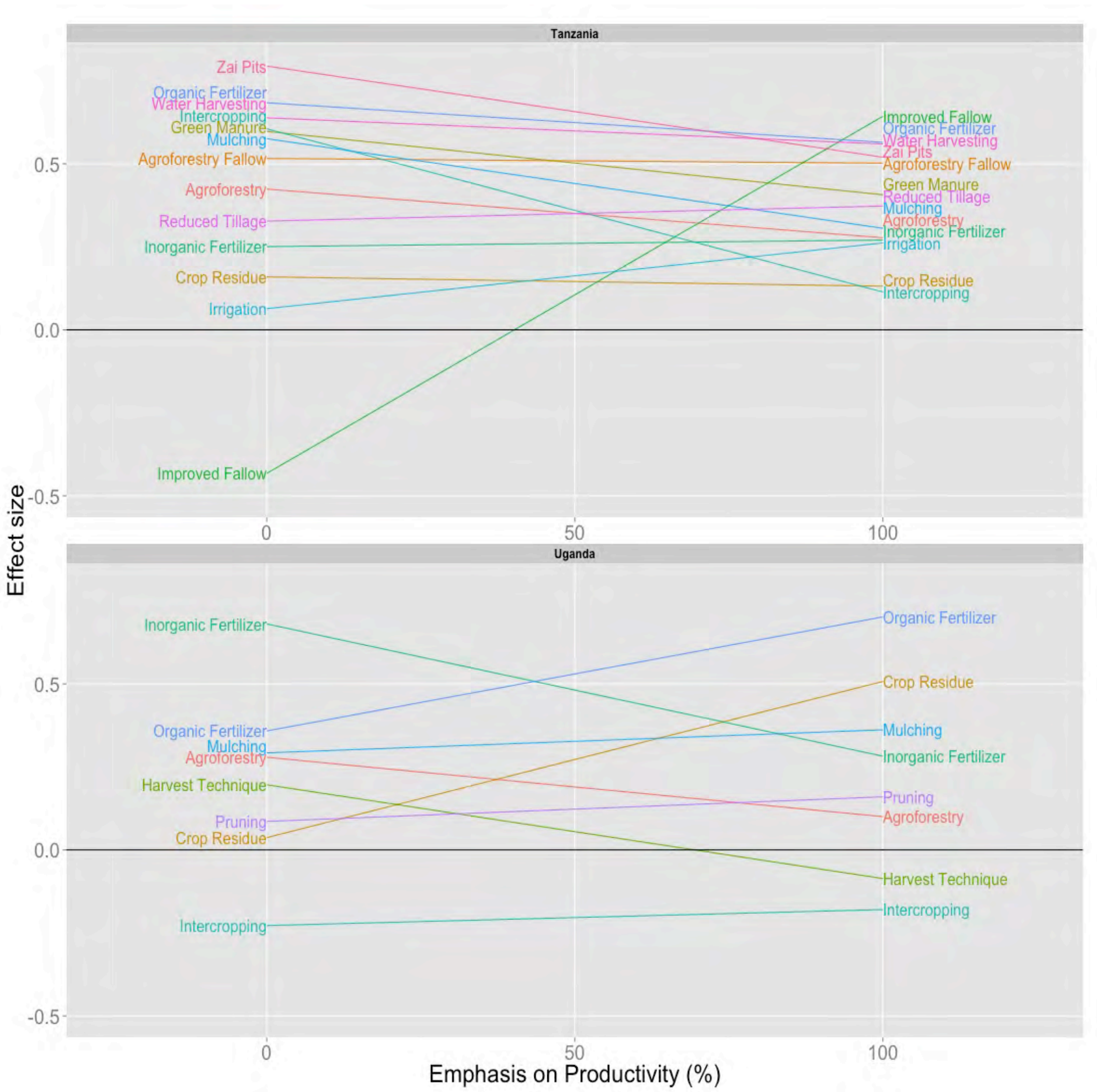

Figure 5: *Ranking of CSA practices by effect size on productivity and resilience indicators in Tanzania (top panel) and Uganda (bottom panel). When emphasis on productivity is 100%, ranking reflects only the weighted mean effect size on productivity indicators. When emphasis on productivity is 0%, ranking reflects only weighted mean effect size on resilience indicators. 50% reflects an equal emphasis on productivity and resilience. Note different scales on the y-axis for each country.*

Discussion

Data Availability

There is substantial empirical evidence available on the effectiveness of potential climate-smart agricultural practices to increase productivity and improve climate change resilience in smallholder farms in East Africa (e.g. REFs). However, there are still significant gaps in the available evidence. Most importantly, there is very little data available on the mitigation potential of most CSA practices in East Africa; only two practices in our dataset had mitigation outcomes reported [18,19]. Additionally, not all crops, practices, and farming systems in East Africa are well represented in the research literature, nor are data of a particular practice and system representative of a long period of time that would allow identifying Management-by-Environment interactions. While a large amount of work has been done on the impact of various fertilizers on maize yield, comparatively little has been done on other important crops, livestock, and promising practices in the region [20]. Despite these limitations in the available evidence for the impact of CSA in East Africa, pooling the existing evidence into one dataset and meta-analysis allows a novel approach for empirical evaluation of CSA options for agricultural development in the region.

The grey literature, particularly reports published by universities and national and international research institutions, contributes significantly to the pool of available information on CSA in the region, doubling the amount of data retrieved and adding novel practices and crops to an otherwise more limited evidence base. While grey literature is typically included in meta analyses to ameliorate a bias towards publishing only “big impact” results [16], we found no such publication bias in effect sizes between the grey and peer-reviewed literature we analyzed (Fig. 3). Indeed, grey literature effect sizes tended to be larger than peer-review reported values for the same practice, location and outcome combinations, suggesting a potential lack of quality control within the grey literature data. Additionally, access to grey literature is somewhat limited. In person visits revealed that the majority of institutions did not have readily accessible grey literature in the form of searchable repositories. For those that did have available documents, challenges encountered included concern over data sharing, data only existing in hard copy form, or studies lacking quantitative data on non climate-smart practices (controls) or on project outcomes. Therefore, while the inclusion of grey literature can expand the pool of available information on CSA in a location, there are trade-offs in the amount of time and effort required to obtain that information, and the quality of the resulting data.

Making CSA Investment Priorities

The outcomes of practices across the three pillars of CSA are variable and context-specific, even within the East Africa region. Similar results have been seen in other regions, such as the Sahel, where some climate-smart practices such as green manure significantly improve maize yield, while others such as parkland agroforestry tend to decrease maize yields [21]. Furthermore, a practice that improves yield of one cereal crop (e.g. green manure for maize yield), does not necessarily improve the yield of another in the same region (green manure for millet). Some of this variability in the impact of practices on productivity and resilience stems from differences in climate and soil conditions. For example, conservation agriculture has been shown to improve maize yield in drier conditions, but decrease maize yields in more humid conditions [22]. Such climatic conditions may account for some of the observed difference between agroforestry impact on productivity indicators in Uganda (negative) and Tanzania (positive).

In addition to the variability in outcomes that stems from differences in biophysical conditions, uncertainty also arises from other sources, including weather fluctuations, variation in implementation efficacy or extent, adoption rates, and external risks such as conflict or market fluctuations. Planning for average conditions may result in unintended outcomes, as average conditions rarely occur now and are likely to become less common with climate change [23]. A likelihood approach such as the one used in this study allows decision makers to consider not only the best-case scenarios for an agricultural intervention, but the full range of possible outcomes from an agricultural practice including the likelihood of extreme outcomes. Additionally, ground-truthing of the likelihood-based results presented here in piloting sites of different agro-ecologies and farming systems would also be needed in order to allow better-informed decisions.

When prioritizing CSA options for investment and implementation, decision makers need to consider factors other than possible impact alone, particularly the potential uptake of each option. Low adoption rates of CSA practices are a major barrier to increased productivity and other CSA benefits [24], and adoption is often difficult to predict using socioeconomic and biophysical variables [25]. Our analysis shows that including realistic adoption rates for CSA practices alters the potential impact on crop productivity at national levels. The practices most likely to double maize yields are not those that deliver the largest increase in yield alone, rather they are the practices that deliver increases in yield *and* are highly adoptable. The practices analyzed here were among the most studied and promoted in Tanzania and Uganda, suggesting that adoption of even more novel practices that do not have an established history in the region will be even more challenging. Thus decision makers may choose to prioritize practices based on the best-case scenario of wide-scale adoption, or on which practices are likely to create the greatest gains given realistic adoption scenarios.

Conclusion/Recommendations

Contrary to expectations and despite some gaps, our analysis shows there is already ample empirical evidence available on the impact of climate-smart agricultural practices on productivity, resilience, and to a lesser extent mitigation benefits in East Africa to help inform planning and policy processes. We have shown in this study that there is likely no "best bet" practice that is the highest performer among candidate practices across productivity resilience, and mitigation outcomes. Existing data for mitigation indicators precluded the inclusion of mitigation as a CSA outcome in an explicit manner in our analysis. However, the available evidence suggests that the highest impact practices are unlikely to be the same for both productivity and resilience. Furthermore, when considering CSA options for scaling-up, potential adoption rates can significantly enhance or limit CSA benefits. Instead, decision makers must choose which priorities are most relevant to their desired outcomes, or choose to scale-up multiple practices to achieve multiple benefits.

Methods

Study Location

Two countries in East Africa were selected as the focus of this meta-analysis, namely Uganda and Tanzania. We chose to focus on these countries for a number of reasons. First, they capture the breadth of farming systems within East Africa, from dryland pastoral systems, to mixed-maize farming, to highland tea and coffee production, to lowland rice and sugarcane production. Second, they are representative of the development challenges and trajectories in the region. Uganda and Tanzania are agrarian societies exhibiting high rural poverty and significant population growth, which can be seen as emblematic for much of the continent. Third, they have robust national agricultural research programs and longstanding extension services. This suggests that there might be large amounts of evidence and research, in both the peer-reviewed and grey literature on potential CSA practices in these countries to form the basis of a meta-analysis. Finally, both Uganda and Tanzania have strong political support for CSA. Ministries of Agriculture and Environment in both countries have created national-level CSA programmes, and out-scaling of CSA is mentioned as a development objective in other policies (e.g. Tanzania's Agricultural Climate Resilience Plan). Tanzania has also established a CSA Task Force to oversee and implement CSA objectives in the country. These types of activities place Tanzania and Uganda at the forefront of action around CSA in sub-Saharan Africa, and thus provide a litmus test for both the opportunities and challenges other countries in the region might face.

Systematic Review

Scope and Methods

We compiled and assessed the peer-reviewed and grey literature on potential climate-smart agriculture practices to determine the effect size of a practice on productivity, resilience, and mitigation. Peer-reviewed literature containing evidence of CSA impact in Tanzania and Uganda was gathered through a systematic review of the English-language literature available from Web of Science [15]. Seventy-three priority CSA practices were identified through interviews with research organizations, international NGOs, development partners, and government institutions, and formed the basis of our search. Indicators of the outcomes of CSA practices were similarly selected through stakeholder interviews to represent as many dimensions of productivity (product yield, biomass, income, labour, etc.), resilience (biophysical, economic, and social resilience), and mitigation (GHG emissions, carbon storage, fuel consumption, etc.) as possible. Full details of the systematic review process, including practice definitions, descriptions of outcome indicators, and search strings can be found in ref. [15] and Appendix I. Initial searches were followed up with a recursive search, by locating all of the cited references from each identified study located in the two countries. In total, searches returned approximately 459 references potentially relevant for CSA in Tanzania, and 315 in Uganda.

In order to locate relevant grey literature on CSA in Tanzania and Uganda, we identified and physically visited 49 institutions deemed likely to have reports, dissertations, or other relevant documents in Tanzania, and 15 in Uganda (see Appendix VI for a list of visited institutions in each country). Potentially relevant documents were photographed, as most could not be physically removed from the institutions and did not exist in digital format.

Screening and Data Extraction

All literature identified via the peer-reviewed and grey literature searches were then screened for inclusion in this study. In order to be included in this meta-analysis, a study had to meet the following six criteria: 1) The study must include one of the 73 chosen practices, 2) It must include data on at least one indicator of CSA outcomes, 3) It must be a field-level study, 4) It must contain primary data, as opposed to model outputs or review data, 5) It must include an appropriate control or non-CSA practice as a comparator, and 6) It must be located in Tanzania or Uganda. References identified from the initial searches and grey literature capture were first screened by title and abstract against these criteria, and references appearing to meet the criteria were further screened in full text. We were unable to locate full text for approximately 11% of the references due to a lack of institutional access to the journal or a lack of digital versions of the article (mainly for those published prior to 2000 in some journals). These references were necessarily excluded from the analysis. Full citations of all the studies included in this meta-analysis are included in Appendix VII.

From each included study, we extracted data on location, environmental conditions, experimental design, and outcomes. Location data included reported latitude, longitude, and elevation of study locations, or the same information from named locations extracted from Google Earth if no latitude and longitude were given. Environmental information included reported mean annual temperature and precipitation, soil classification and texture, as well as basic soil properties including soil carbon and pH. Experimental design information included descriptions and coded categorization of the treatment and control practices, the number of replicates reported, and the duration of the experiment in years. For information about CSA outcomes, we included the object of the experiment (e.g. the crop, livestock breed or product, soil, tree species, etc.), the indicator of outcome reported (e.g. yield, net income, soil carbon, water use efficiency, GHG emissions, etc.) with the units, the treatment value, the control value, and standard deviation if reported. Where the outcomes were reported for soil (such as soil carbon, soil moisture, etc.) depth of the measurement was also recorded.

Data Analysis

We calculated the effect size of CSA practices on outcomes using the log response ratio (*L*):

$$L = \ln(\frac{\bar{X}_T}{\bar{X}_C})$$

where, *L* equals the natural logarithm of the measured mean outcome under the CSA practice (X_T) relative to the mean outcome under the control practice (X_c) [26]. Very few studies in our sample reported standard deviations; therefore each observation was weighted by the number of replications per study (n_{rep}) [27], and inversely weighted by the number of observations per study (n_{obs}) [22]:

$$(w) = \frac{{n_{rep}}^2}{2n_{rep} \times n_{obs}}$$

This assures that studies reporting multiple outcomes do not overly bias the results. As some practices were represented with many observations in the dataset and others by only a few, we estimated the mean and uncertainty in effect size per combination of practice, outcome, and location via bootstrapping. For each combination of practice, outcome, and location (e.g. productivity outcomes for agroforestry in Tanzania), we chose a random sample of *n* observations with replacement, where *n* is the number of observation for that practice/outcome/location combination, and calculated a weighted mean. Random selection was repeated 1000 times to determine a mean effect size of the practice on the outcome and variance around that mean.

The probability distributions of potential yield for major crops in Tanzania and Uganda under various CSA management practices were generated by Monte Carlo simulation using the following formula:

$$Y_p = Y_c \times (e^L \times a + (1 - a))$$

where Y_p is the potential yield under CSA, Y_c is the current yield, e^L is the response ratio, and a is the adoption rate of that CSA practice. For current crop yields we used the mean and standard deviation from the area-weighted mean smallholder maize yield reported in the respective national agricultural census data [28,29]. Mean and variance in adoption rates for different CSA practices were taken from national census data, as well as community level adoption studies at various sites within Tanzania [30-32], and Uganda [33-36]. Response ratios for CSA practices were calculated as above using only outcomes for product yield. For each Monte Carlo run, we chose a random value of Y_c and L from normal distributions, and a from a truncated normal distribution (0-100%), and calculated the resulting potential yield Y_p. This process was repeated 1000 times to generate probability distributions of crop yield under CSA with and without adoption rates.

References

1. Lobell DB and SM Gourdji. 2014. The influence of climate change on global crop productivity. Plant Physiology **160**(4):1686-1697.
2. Licker R, M Johnston, JA Foley, C Barford, CJ Kucharik, C Monfreda, and N Ramankutty. 2010. Mind the gap: how do climate and agricultural management explain the 'yield gap' of croplands around the world? *Global Ecology and Biogeography* **19**: 769-782.
3. Lobell DB, KG Cassman and CB Field. 2009. Crop yield gaps: their importance, magnitudes, and causes. *Annual Review of Environment and Resources* **34**: 179-204.
4. IPCC. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, RK Pachauri and LA Meyer (eds.)]. IPCC, Geneva, Switzerland.
5. IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field CB, V Barros, TF Stocker, D Qin, DJ Dokken, KI Ebi, MD Mastrandrea, KJ Mach, GK Plattner, SK Allen, M Tignor and PM Midgley (eds.)]. Cambridge University Press, UK and New York, NY, USA, 582 pp.
6. Challinor AJ, J Watson, DB Lobell, SM Howden, DR Smith, and N Chhetri. 2014. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change* **4**(4): 287-291.

7. Thornton PK, PG Jones, G Alagarswamy, and J Andresen. 2009. Spatial variation of crop yield response to climate change in East Africa. *Global Environmental Change* **19**: 54-65.
8. Ramirez-Villegas J and PK Thornton. 2015. Climate change impacts on African crop production. *CCAFS Working Paper* no. 119. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at www.ccafs.cgiar.org.
9. FAO. 2013. *Climate-Smart Agriculture Sourcebook.* Food and Agriculture Organization of the United Nations. Rome, Italy.
10. Lipper L, P Thornton, B Campbell, et al. 2014. Climate-smart agriculture for food security. *Nature Climate Change* **4**: 1068-1072
11. Kihara, J, A Bationo, B Waswa, JM Kimetu, B Vanlauwe, J Okeyo, J Mukalama, and C Martius. 2012. Effect of reduced tillage and mineral fertilizer application on maize and soybean productivity. *Experimental Agriculture* **48**(2): 159-175.
12. Thierfelder C, M Mutenje, A Mujeyi, and M Mupangwa. 2015. Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe. *Food Security* **7**:15-31.
13. All Climate-Smart Agriculture Country Plans may be downloaded from http://canafrica.com/tag/framework/
14. CCAFS. 2015.Shaping resilient food system policies for successful climate adaptation in East Africa. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
15. Rosenstock TS, C Lamanna, S Chesterman, et al. 2015. The scientific basis of climate-smart agriculture: A systematic review protocol. *CCAFS Working Paper* no. 136. CGIAR Research Program on Climate Change, Agriculture and Food

Security (CCAFS). Copenhagen, Denmark. Available online at www.ccafs.cgiar.org.

16. McAuley L, B Pham, P Tugwell and D Moher. 2000. Does the inclusion of grey literature influence estimates of intervention effectiveness reported in meta-analyses? *The Lancet* **356**(9237):1228-1231.
17. HarvestChoice. 2015. *Farming System (names)*. International Food Policy Research Institute, Washington, DC, and University of Minnesota, St. Paul, MN. Available online at http://harvestchoice.org/data/fs_2012.
18. Kimaro AA, M Mpanda, J Rioux, E Aynekulu, S Shaba, M Thiong'o, P Mutuo, S Abwanda, K Shepherd, H Neufeldt, and TS Rosenstock. 2015. Is conservation agriculture 'climate-smart' for maize farmers in the highlands of Tanzania? *Nutrient Cycling in Agroecosystems*. DOI: 10.1007/s10705-015-9711-8
19. Hickman JE, RJ Scholes, TS Rosenstock, C Pérez Garcia-Pando, and J Nyamangara. 2014. Assessing non-CO_2 climate-forcing emissions and mitigation in sub-Saharan Africa. *Current Opinion in Environmental Sustainability* **9-10**:65-72.
20. Thornton PK, T Rosenstock, W Förch, C Lamanna, P Bell, B Henderson, and M Herrero. A qualitative evaluation of CSA options in mixed crop-livestock systems in developing countries. In: *Climate Smart Agriculture – Building Resilience to Climate Change.* Elsevier. (D Zilberman, L Lipper, N McCarthy, S Asfaw and G Branca editors). *In preparation, anticipated publication 2016*.
21. Bayala J, GW Sileshi, R Coe, A Kalinganire, Z Tchoundjeu, F Sinclar and D Garrity. 2012. Cereal yield response to conservation agriculture practices in drylands of West Africa: A quantitative synthesis. *Journal of Arid Environments* **78**:13-25.
22. Pittelkow C et al. 2015. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **517**: 365-368.

23. Rosenzweig C, A Iglesias, XB Yang, PR Epstein, and E Chivian. 2001. Climate change and extreme weather events; Implications for food production, plant diseases, and pests. *Global Change and Human Health* **2**(2): 90-104.

24. Feder G, RE Just and D Zilberman. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change* **33**(2):255-298.

25. Knowler D and B Bradshaw. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy* **32**: 25-48.

26. Hedges LV, J Gurevitch and PS Curtis. 1999. The meta-analysis of response ratios in experimental ecology. *Ecology* **80**: 1150–1156.

27. Adams DC, J Gurevitch and MS Rosenberg. 1997. Resampling tests for meta-analysis of ecological data. *Ecology* **78**: 1277-1283.

28. Uganda Bureau of Statistics and Ministry of Agriculture, Animal Industry, and Fisheries. 2010. *Uganda Census of Agriculture 2008/2009, Volume IV: Crop Area and Production Report.*

29. United Republic of Tanzania, Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock Development and Fisheries, Ministry of Water and Irrigation, Ministry of Agriculture, Livestock and Environment, Zanzibar, Prime Minister's Office, Regional Administration and Local Governments, Ministry of Industries, Trade and Marketing, The National Bureau of Statistics and the Office of the Chief Government Statistician, Zanzibar. 2012. *National Sample Census of Agriculture 2007/2008: Small Holder Agriculture, Volume II: Crop Sector - National Report*.

30. Belotti F, A Arslan, and L Lipper. *In Press*. Smallholder productivity under climatic variability: Adoption and impact of widely promoted agricultural practices in Tanzania.

31. Mwongera C, KM Shikuku, L Winowiecki, W Okolo, J Twyman, and P Läderach. 2014. *Climate Smart Agriculture Rapid Appraisal Report from the Southern Agricultural Growth Corridor of Tanzania.*
32. Peterson CA, M Nyasimi, and P Kimeli. 2014. *Local-level appraisal of benefits and barriers affecting adoption of climate-smart agricultural practices: Lushoto, Tanzania*. Technical report for the CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS).
33. Kyazze FB and P Kristjanson. 2011. Summary of baseline household survey results: Rakai District, South Central Uganda. CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS). Copenhagen, Denmark. Available online at: http://ccafs.cgiar.org/resources/baseline-surveys
34. Mubiru DN and P Kristjanson. 2012. Summary of baseline household survey results: Hoima District, West Central Uganda. CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS). Copenhagen, Denmark. Available online at: http://ccafs.cgiar.org/resources/baseline-surveys
35. Sanginga PC, RN Kamugisha, and AM Martin. 2007. Conflicts management, social capital and adoption of agroforestry technologies: empirical findings from the highlands of southwestern Uganda. *Agroforestry Systems* **69**: 67-76.
36. Mugonola B, J Deckers, J Poesen, M Isabirye and E Methijs. 2013. Adoption of soil and water conservation technologies in the Rwizi catchment of south western Uganda. *International Journal of Agricultural Sustainability* **11**(3): 264-281.

Appendices

Appendix I: CSA Technologies and Outcomes

CSA Technologies		
Theme	**Practice**	**Subpractice**
Agroforestry	Intercropping	Leguminous tree intercropping
		Nonleguminous tree intercropping
	Fallows	Agroforestry Fallows
	Tree Management	Pruning
		Coppicing
		Tree prunings applied to crops
	Silvopasture	Silvopasture, Agrosilvopasture
Agronomy	Soil Management	Conservation Agriculture
		Reduced Tillage
		Improved Fallows (e.g. with leguminous cover crops)
		Crop Residue retention/incorporation
		Mulching
		Green Manure
		BioChar
		pH Management (e.g. liming)
	Water Management	Irrigation
		Water Harvesting (e.g. bunds, contours, terraces)
		Zai/Planting pits
		Rice Management (e.g. SRI, AWD)
	Nutrient Management	Inorganic Fertilizer (e.g. NPK, Urea)
		Organic Fertilizer (e.g. Manure)
		Integrated Nutrient Management
	Crop Management	Crop Rotation
		Intercropping
		Improved Varieties
		Increased Farm Diversity (e.g. in rotations)
Livestock	Diet Management	Improved Supplements
		Improved Protein
		Improved Digestibility
	Pasture Management	Fodder Shrubs
		Forage Legumes
		Rotational Grazing
	Manure Management	Manure Collection and Storage
		Manure Treatment
	Breed Management	Hybridization
		Assisted Reproduction
		Improved Breeds
Postharvest	Harvest Management	Improved Harvest Time
		Improved Harvest Technique
	Postharvest Storage	Improved Storage
		Improved Preservation/Drying
Energy	Cookstoves	Improved Cookstoves
	Biogas	Biogas

CSA Outcomes		
Pillar	**Indicator**	**Subindicator**
Productivity	Product Yield	Crop Yield
		Animal Weight Gain
		Animal Product Yield
		Land Equivalent Ratio
	Non-Product Yield	Crop Residue Produced
		Biomass Yield
	Income	Gross Returns
		Net Returns
		Benefit/Cost Ratio
	Costs	Production Costs
		Cost/Benefit Ratio
	System Performance	Net Present Value (NPV)
		Internal Rate of Return (IRR)
		Marginal Rate of Return (MRR)
		Payback Period
Resilience	Soil Quality	Soil Carbon
		Soil Moisture
		Soil Nutrients (e.g. N, P)
		Bulk Density
		Erosion and Runoff
	Pest & Pathogen damage	Pest Loads
		Pest Damage/Losses
	Biodiversity	Beneficial Organisms
		Species Richness
	Labour	Person-hours
		Value of Labour
	Gender	Women's Labour
		Women's Income
	Efficiency	Nutrient Use Efficiencies
		Water Use Efficiency
		Total Factor Productivity
		Feed Conversion Ratio
		Protein Conversion Ratio
Mitigation	GHG Emissions	CO_2, CH_4, NO_x Emissions
		Emissions Intensity
	Carbon Stocks	Total Soil Carbon
		Total Aboveground Biomass
	Fuel Use	Fuel Consumed
		Fuel Saved

Appendix II: Effect size of CSA subpractices on CSA pillars.

		Effect Size by Outcome Pillar[1]		
Theme	Subpractice	Productivity	Resilience	Mitigation
		-Tanzania-		
Agronomy	Conservation Agriculture	$0.84 \pm 0.47_{(2,14)}$		
	Crop Residue	$0.13 \pm 0.23_{(6,66)}$	$0.16 \pm 0.12_{(1,15)}$	$-0.56 \pm 0.35_{(2,28)}$
	Crop Rotation	$0.23 \pm 0.39_{(6,39)}$		
	Deficit Irrigation	$0.26 \pm 0.79_{(4,93)}$	$0.06 \pm 0.82_{(4,143)}$	
	Green Manure	$0.41 \pm 0.52_{(8,131)}$	$0.60 \pm 0.59_{(5,28)}$	$-0.20 \pm 0.35_{(1,10)}$
	Improved Fallow	$0.64 \pm 0.36_{(2,68)}$	$-0.43 \pm 0.15_{(1,6)}$	
	Improved Varieties	$0.13 \pm 0.58_{(12,268)}$	$1.14 \pm 1.43_{(1,4)}$	
	Inorganic Fertilizer	$0.27 \pm 0.71_{(44,1340)}$	$0.26 \pm 0.43_{(6,51)}$	$-0.31 \pm 0.36_{(1,18)}$
	Intercropping	$0.11 \pm 0.56_{(6,88)}$	$0.61 \pm 1.11_{(1,32)}$	
	pH Management	$0.94 \pm 0.64_{(1,6)}$		
	Mulching	$0.31 \pm 0.40_{(2,13)}$	$0.58 \pm 1.22_{(1,27)}$	
	Organic Fertilizer	$0.57 \pm 0.39_{(20,376)}$	$0.68 \pm 1.01_{(6,98)}$	$-0.20 \pm 0.35_{(1,10)}$
	Reduced Tillage	$0.37 \pm 0.41_{(11,213)}$	$0.33 \pm 0.44_{(6,59)}$	$-0.10 \pm 0.27_{(1,10)}$)
	Rice Management	$1.08 \pm 0.68_{(3,14)}$		
	Water Harvesting	$0.56 \pm 0.43_{(9,97)}$	$0.64 \pm 0.86_{(5,82)}$	
	Zai Pits	$0.52 \pm 0.27_{(3,8)}$	$0.79 \pm 0.36_{(2,5)}$	
Agroforestry	Leguminous Intercropping	$0.08 \pm 0.58_{(11,197)}$	$0.49 \pm 1.12_{(5,49)}$	
	Non-leguminous Intercropping	$0.45 \pm 0.80_{(4,67)}$	$0.25 \pm 0.81_{(1,20)}$	
	Tree prunings applied	$0.28 \pm 0.47_{(7,82)}$	$0.03 \pm 0.32_{(2,16)}$	
	Agroforestry Fallows	$0.50 \pm 0.18_{(2,22)}$	$0.52 \pm 0.30_{(1,5)}$	
Livestock	Improved Protein	$0.36 \pm 0.29_{(4,17)}$	$-0.44 \pm 0.26_{(2,6)}$	
	Improved Supplements	$0.24 \pm 0.35_{(11,69)}$	$0.61 \pm 1.11_{(2,6)}$	
	Rotational Grazing	$0.28 \pm 0.23_{(2,11)}$		
	Fodder Shrubs	$0.31 \pm 053_{(9,59)}$	$-0.15 \pm 0.03_{(1,3)}$	
	Forage Legumes	$0.51 \pm 0.26_{(1,3)}$		
Postharvest	Improved Storage	$0.44 \pm 0.45_{(1,3)}$		
Energy	Biogas	$2.41 \pm 1.15_{(2,20)}$	$1.75 \pm 1.16_{(2,5)}$	$2.13 \pm 1.01_{(2,12)}$
	Improved Cookstoves			$0.46 \pm 0.15_{(1,6)}$
		-Uganda-		
Agronomy	Biochar	$0.20 \pm 0.21_{(1,9)}$		
	Crop Residue	$0.51 \pm 0.71_{(4,46)}$	$0.04 \pm 0.01_{(1,2)}$	
	Crop Rotation	$0.27 \pm 0.41_{(6,114)}$		
	Green Manure	$0.38 \pm 0.36_{(6,103)}$	$-0.18 \pm 0.35_{(2,9)}$	
	Improved Fallow	$0.42 \pm 0.37_{(4,31)}$		
	Improved Varieties		$1.07 \pm 0.27_{(1,4)}$	
	Inorganic Fertilizer	$0.28 \pm 0.57_{(22,1145)}$	$0.68 \pm 1.08_{(3,12)}$	
	Intercropping	$-0.18 \pm 0.25_{(2,20)}$	$-0.23 \pm 0.26_{(1,3)}$	
	Mulching	$0.36 \pm 0.72_{(6,69)}$	$0.29 \pm 0.20_{(2,12)}$	
	Organic Fertilizer	$0.70 \pm 0.73_{(12,302)}$	$0.36 \pm 0.50_{(3,9)}$	
	Reduced Tillage	$0.86 \pm 0.71_{(1,10)}$		
Agroforestry	Leguminous Intercropping	$-0.25 \pm 0.49_{(3,32)}$	$0.10 \pm 0.26_{(2,55)}$	
	Non-leguminous Intercropping	$0.14 \pm 0.38_{(3,32)}$	$0.49 \pm 0.29_{(2,21)}$	
	Tree prunings applied	$0.16 \pm 0.37_{(2,65)}$	$0.09 \pm 0.18_{(1,8)}$	
	Agroforestry Fallows		$0.67 \pm 0.07_{(1,4)}$	
Livestock	Improved Protein	$1.03 \pm 0.76_{(3,5)}$		
	Fodder Shrubs	$0.95 \pm 0.79_{(3,5)}$		
	Manure Management	$0.45 \pm 0.26_{(1,5)}$		
	Rotational Grazing	$1.88 \pm 2.21_{(2,6)}$		
Postharvest	Harvest Technique	$-0.09 \pm 0.22_{(1,3)}$	$0.20 \pm 0.28_{(1,8)}$	
	Improved Storage	$-0.08 \pm 0.14_{(1,7)}$	$-0.21 \pm 0.29_{(1,10)}$	
Energy	Improved Cookstoves			$0.36 \pm 0.39_{(2,8)}$

[1]*Numbers in brackets show the number of studies and the number of data points behind each response ratio.*

Appendix III: Effect size of CSA practices on CSA indicators in Tanzania

		Effect Size by Indicator											
			Productivity					Resilience				Mitigation	
Theme	Subpractice	Product Yield	Non-Product Yield	Income	* Costs	System Perfor-mance	* Labour	Soil Quality	Efficiency	* Pests & Disease	* Emissions	Carbon Stocks	* Fuel Use
Agronomy	Conservation Agriculture	0.85			0.76								
	Crop Residue	0.12	0.29					0.16			-0.66	0.09	
	Crop Rotation	0.24	-0.01										
	Green Manure	0.27	0.78	-0.05			-0.48	0.16	0.56	1.15	-0.49	0.09	
	Improved Fallow	0.68	0.71	-0.14			-0.43						
	Improved Varieties	0.98						-0.96					
	Fertilizer, Inorganic	0.49	0.37	-0.14	-0.30		-0.08	0.01	0.63	0.29	-0.31		
	Fertilizer, Organic	0.58	0.38	0.45	-0.35		0.84	0.73	0.41		-0.49	0.09	
	Intercropping	0.11						0.61					
	Irrigation	0.59	-0.25	0.17			0.93		0.00				
	pH Management	0.94											
	Mulching	0.39	0.08				0.84		0.44				
	Reduced Tillage	0.43	-0.07	-0.04				0.09	0.78	0.67	-0.24	0.04	
	Rice Management	1.08											
	Water Harvesting	0.56		0.50				0.64	0.35				
	Zai Pits	0.52							0.79				
Agroforestry	Leguminous tree intercropping	0.07	0.02	0.76				0.49					
	Non-leguminous tree intercropping	0.45	-0.30	1.09	-0.22			0.25					
	Tree prunings applied	0.28						0.03					
	Agroforestry Fallow	0.50	0.48					0.52					
Livestock	Improved Protein	0.16		0.01	0.13				-0.24				
	Improved Supplements	0.24		0.29	0.28				-0.15				
	Fodder Shrubs	0.32		0.09	-0.23				-0.15				
	Forage Legumes	0.51											
Postharvest	Improved Storage			0.68	-0.04								
Energy	Biogas				2.42		1.76				2.30		2.06
	Improved Cookstoves												-0.46

Appendix IV: Effect size of CSA practices on CSA indicators in Uganda

		Effect Size by Indicator											
			Productivity					Resilience				Mitigation	
Theme	Subpractice	Product Yield	Non-Product Yield	Income	* Costs	System Perfor-mance	* Labour	Soil Quality	Efficiency	* Pests & Disease	* Emissions	Carbon Stocks	* Fuel Use
Agronomy	Biochar		0.20										
	Crop Residue	0.44	0.05	1.10				0.04					
	Crop Rotation	0.17	0.66	0.16									
	Green Manure	0.43	0.42	0.10		0.65	-0.23			0.70			
	Improved Fallow	0.44	0.62	0.04		0.65							
	Fertilizer, Inorganic	0.29	0.36	0.30		0.08		0	0.90	0.96			
	Fertilizer, Organic	0.56	0.98	0.69				-0.04	0.54	0.87			
	Intercropping	-0.18					-0.23						
	Mulching	0.48	1.3	0.39		0.08		0.31	-0.26	0.26			
	Reduced Tillage	0.53		2.17									
Agroforestry	Leguminous Intercropping	-0.25						0.10					
	Non-leguminous Intercropping	-0.10		0.44				0.49					
	Tree prunings applied	0.16						0.09					
	Agroforestry Fallows							0.67					
Livestock	Fodder Shrubs	0.95											
	Forage Legumes	0.42											
	Manure Management		0.45										
	Rotational Grazing	1.26	2.05										
	Silvopasture	0.81											
Postharvest	Harvest Technique	-0.09								0.20			
Energy	Improved Cookstoves												0.1

**All signs indicate an improvement (+) or worsening (-) of the indicator. For the indicators marked with a star (*), positive values indicate a lowering of that quantity (sucha s costs, labour, or GHG emissions), while negative values show an increase.*

Appendix V: Potential yields of crops under CSA

Crop	% HHs[1]	Area[1] (10^6 ha)	Yield[1,2] (t/ha)	Subpractice	Response Ratio[3]	Adoption (%)[4]	Potential Yield (t/ha)
				-Tanzania			
Maize	87.5%	4.09	1.33 ± 0.28	Agroforestry	-0.13 ± 0.52 $_{(12,98)}$	13 ± 8%	1.35 ± 0.31
				Agroforestry Fallows	0.50 ± 0.18 $_{(2,17)}$	34 ± 10%	1.64 ± 0.39
				Crop Residue	0.17 ± 0.28 $_{(4,36)}$	34 ± 15%	1.45 ± 0.37
				Crop Rotation	0.02 ± 0.49 $_{(3,26)}$	36 ± 30%	1.40 ± 0.44
				Green Manure	0.28 ± 0.36 $_{(7,70)}$	7 ± 7%	1.39 ± 0.30
				Improved Fallow	0.68 ± 0.3 $_{(2,31)}$	34 ± 10%	1.84 ± 0.51
				Improved Varieties	0.18 ± 0.15 $_{(7,147)}$	13 ± 10%	1.37 ± 0.30
				Inorganic Fertilizer	0.56 ± 0.57 $_{(31,825)}$	32 ± 33%	1.84 ± 0.88
				Intercropping	0.23 ± 0.60 $_{(5,71)}$	57 ± 16%	1.71 ± 0.95
				Organic Fertilizer	0.63 ±0.31 $_{(11,126)}$	15 ± 13%	1.55 ± 0.41
				Reduced Tillage	0.47 ± 0.35 $_{(9,140)}$	24 ± 8%	1.54 ± 0.39
				Water Harvesting	0.56 ± 0.43 $_{(6,63)}$	20 ± 13%	1.57 ± 0.44
				Zai Pits	0.51 ± 0.43 $_{(3,7)}$	20 ± 13%	1.52 ± 0.38
Legumes	46.8%	1.48	0.72 ± 0.11	Agroforestry	0.49 ± 0.72 $_{(5,40)}$	13 ± 8%	0.82 ± 0.25
				Improved Varieties	1.39 ±0.22 $_{(1,6)}$	13 ±10%	1.05 ± 0.26
				Inorganic Fertilizer	0.20 ± 0.31 $_{(11,175)}$	32 ± 33%	0.80 ± 0.19
				Organic Fertilizer	0.51 ± 0.71 $_{(5,96)}$	15 ± 13%	0.88 ± 0.39
				Reduced Tillage	-0.18 ± 0.22 $_{(2,12)}$	24 ± 8%	0.70 ± 0.11
				Water Harvesting	0.62 ± 0.64 $_{(3,17)}$	20 ± 13%	0.92 ± 0.35
Tubers	32.1%	0.29	1.94 ± 0.48	Agroforestry	0.52 ± 0.56 $_{(3,12)}$	13 ± 8%	2.15 ± 0.67
				Crop Residue	0.16 ± 0.15 $_{(1,3)}$	34 ± 15%	2.04 ±0.51
				Improved Varieties	-0.47 ± 0.85 $_{(2,49)}$	13 ± 10%	1.93 ± 0.54
				Inorganic Fertilizer	0.03 ± 0.34 $_{(1,3)}$	32 ± 33%	2.03 ± 0.62
Rice	19.9%	0.91	1.58 ± 0.45	Crop Rotation	0.54 ± 0.19 $_{(2,7)}$	36 ± 30%	2.10 ± 0.70
				Improved Varieties	0.14 ± 0.69 $_{(1,42)}$	13 ± 10%	1.69 ± 0.56
				Inorganic Fertilizer	0.66 ± 0.63 $_{(3,40)}$	32 ± 33%	2.45 ± 1.62
				Organic Fertilizer	0.27 ± 0.10 $_{(2,4)}$	15 ± 13%	1.67 ± 0.49
				SRI/AWD	1.08 ± 0.68 $_{(3,14)}$	9 ± 8%	3.00 ± 2.52
				Water Harvesting	0.55 ± 0.42 $_{(2,5)}$	20 ± 13%	1.87 ± 0.62
				-Uganda-			
Maize	49%	1.01	2.34 ± 0.67	Agroforestry	-0.42 ± 0.58 $_{(1,15)}$	16 ± 10%	2.25 ± 0.68
				Crop Residue	0.26 ± 0.30 $_{(1,23)}$	29 ± 28%	2.62 ± 0.86
				Crop Rotation	0.26 ± 0.35 $_{(3,51)}$	31 ± 10%	2.61 ± 0.83
				Green Manure	0.41 ± 0.25 $_{(4,65)}$	7 ± 6%	2.46 ± 0.70
				Inorganic Fertilizer	0.32 ± 0.32 $_{(6,102)}$	5 ± 4%	2.34 ± 0.68
				Improved Fallow	0.43 ± 23 $_{(3,13)}$	4 ± 4%	2.42 ± 0.71
Beans	47%	0.62	1.5 ± 0.3	Agroforestry	-0.22 ± 0.18 $_{(2,33)}$	16 ± 10%	1.46 ± 0.30
				Agroforestry Prunings	0.09 ± 0.16 $_{(2,29)}$	16 ± 10%	1.53 ± 0.31
				Crop Residue	0.23 ± 0.25 $_{(2,5)}$	28 ± 28%	1.66 ± 0.40
				Improved Varieties	0.14 ± 0.55 $_{(5,172)}$	36 ± 26%	1.70 ± 0.65
				Inorganic Fertilizer	0.20 ± 0.38 $_{(6,30)}$	5 ± 4%	1.53 ± 0.31
				Intercropping	-0.14 ± 0.23 $_{(2,14)}$	34 ± 12%	1.43 ± 0.29
				Organic Fertilizer	0.64 ± 0.86 $_{(3,4)}$	21 ± 17%	2.12 ± 1.66
Banana	39%	4.02	5.34 ± 1.12	Inorganic Fertilizer	0.26 ± 0.25 $_{(5,82)}$	5 ± 4%	5.45 ± 1.15
				Mulching	0.47 ± 0.28 $_{(4,29)}$	29 ± 27%	6.70 ± 1.93
				Organic Fertilizer	0.61 ± 0.16 $_{(1,20)}$	21 ± 17%	6.46 ± 1.61
				Agroforestry	-0.06 ± 0.59 $_{(1,2)}$	16 ± 10%	5.43 ± 1.35
Cassava	32%	2.89	3.33 ± 0.22	Improved Varieties	0.48 ± 0.54 $_{(4,315)}$	36 ± 26%	4.58 ± 1.93
				Harvest Timing	-0.09 ± 0.22 $_{(1,43)}$	20 ± 10%	3.29 ± 0.28
				Inorganic Fertilizer	0.25 ± 0.17 $_{(1,29)}$	5 ± 4%	3.38 ± 0.23

[1]Sources: United Republic of Tanzania National Sample Census of Agriculture 2007/2008 and Uganda Census of Agriculture 2008/2009. Area is the sum of area planted under that crop in the long rains and short rains. % Smallholder households (%HHs) is a percentage of total households planting the crop in the long rains and short rains. [2]Yield the mean of yield per region weighted by area. [3] Numbers in brackets show the number of studies and number of data points behind each response ratio. [4]Adoption figures are means of reported adoption rates of practices in each country from sources described in Methods.

Appendix VI: List of Institutions Visited for Grey Literature

Tanzania

Government Institutions: Ministry of Agriculture, Food and Cooperatives: Research and Development, Department of Mechanization, Department of Land Use Planning, Department of Crop Promotion, Department of Special Projects; National Agricultural Research Institutions: Uyole, Naliendele, Ilonga, Seliani, Tumbi, Hombolo, Mikocheni, Mlingano. Nongovernmental Organizations: Tanzania Traditional Energy Development Organization (TaTEDO), World Wildlife Fund Tanzania, CARE Tanzania, Tanzania Forest Conservation Group (TFCG), Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania (MJUMITA), Wildlife Conservation Society Tanzania, African Conservation Tillage Network (ACT-Tanzania), Conservation Farming Unit (CFU-Tanzania), World Vision Tanzania, Catholic Relief Services (CRS Tanzania), Oxfam Tanzania, Concern Tanzania, Vi-Agroforestry, World Vegetable Center Tanzania (AVRDC-Tanzania). Academic Institutions: Sokoine University, University of Dar es Salaam, Ardhi University, Nelson Mandela University, University of Dodoma, Tumaini University, Open University of Tanzania, Sebastian Kolowa Memorial University. Research Organizations: World Agroforestry Centre (ICRAF- Tanzania), Tanzania Commission for Science and Technology (COSTECH), The Centre for Energy, Environment, Science and Technology (CEEST), Policy Research for Development (REPOA), Tanzania Forestry Research Institute (TAFORI), National Forest Resources Management and Agroforestry Centre (NAFRAC). Development Partners: Swedish International Development Cooperation Agency (SIDA), World Bank, International Fund for Agricultural Development (IFAD), African Development Bank (AfDB), German Institute for International Cooperation (GIZ), UK Department for International Development (DFID), United States Agency for International Development (USAID), United Nations Food and Agriculture Organization (FAO), United Nations Development Program (UNDP), Irish AID, The Norwegian Embassy to Tanzania, The Embassy of Finland in Tanzania, Eastern Arc Mountains Endowment.

Uganda

Government Institutions: Kawanda National Agricultural Research Lab, National Crops Resources Research Institute (NaCRRI), National Semi-Arid Resources Research Institute (NaSARRI), National Forestry Resources Research Institute (NaFORRI), National Livestock Resources Research Institute (NaLIRRI). Academic Institutions: Makerere University: Department of Agricultural Production, Department of Environmental Management, Department of Commercial Forestry, Department of Agribusiness. Private Sector: International Fertilizer Development Centre, Coffee Research Institute. Nongovernmental Organizations and Development Partners: World Vision Uganda, United National Development Program (UNDP), International Union for Conservation of Nature (IUCN Uganda), Sasakawa Africa Association.

Appendix VII: Systematic Review Bibliography

Tanzania Peer-Reviewed References

Adkins, E., Tyler, E., Wang, J., Siriri, D. & Modi, V. (2010). Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. *Energy for Sustainable Development* 14(3): 172-185.

Ahimana, C. & Maghembe, J. A. (1987). GROWTH AND BIOMASS PRODUCTION BY YOUNG EUCALYPTUS-TERETICORNIS UNDER AGROFORESTRY AT MOROGORO, TANZANIA. *Forest Ecology and Management* 22(3-4): 219-228.

Baijukya, F. P., de Ridder, N. & Giller, K. E. (2005). Managing legume cover crops and their residues to enhance productivity of degraded soils in the humid tropics: A case study in Bukoba District, Tanzania. *Nutrient Cycling in Agroecosystems* 73(1): 75-87.

Baijukya, F. P., de Ridder, N. & Giller, K. E. (2006). Nitrogen release from decomposing residues of leguminous cover crops and their effect on maize yield on depleted soils of Bukoba District, Tanzania. *Plant and Soil* 279(1-2): 77-93.

Baitilwake, M. A., De Bolle, S., Salomez, J., Mrema, J. P. & De Neve, S. (2011). Effects of manure nitrogen on vegetables' yield and nitrogen efficiency in Tanzania. *International Journal of Plant Production* 5(4): 417-429.

Bitende, S. N. & Ledin, I. (1996). Effect of doubling the amount of low quality grass hay offered and supplementation with Acacia tortilis fruits or Sesbania sesban leaves, on intake and digestibility by sheep in Tanzania. *Livestock Production Science* 45(1): 39-48.

BML, N., ZS, M. & OB, M. (2012). Productivity of the agroforesty systems and its contribution to household income among farmers in Lushoto District, Tanzania. *International Journal of Physical and Social Sciences* 2(7).

Bwire, J. M. N., Wiktorsson, H. & Shayo, C. M. (2004). Effect of level of Acacia tortilis and Faidherbia albida pods supplementation on the milk quality of dual-purpose dairy cows fed grass hay-based diets. *Livestock Production Science* 87(2-3): 229-236.

Chamshama, S. A. O., Mugasha, A. G., Klovstad, A., Haveraaen, O. & Maliondo, S. M. S. (1998). Growth and yield of maize alley cropped with Leucaena leucocephala and Faidherbia albida in Morogoro, Tanzania. *Agroforestry Systems* 40(3): 215-225.

Enfors, E., Barron, J., Makurira, H., Rockstrom, J. & Tumbo, S. (2011). Yield and soil system changes from conservation tillage in dryland farming: A case study from North

Eastern Tanzania. *Agricultural Water Management* 98(11): 1687-1695.

Goromela, E. H., Ledin, I. & Uden, P. (1997). Indigenous browse leaves as supplements to dual purpose goats in central Tanzania. *Livestock Production Science* 47(3): 245-252.

Igbadun, H. E., Salim, B. A., Tarimo, A. K. P. R. & Mahoo, H. F. (2008). Effects of deficit irrigation scheduling on yields and soil water balance of irrigated maize. *Irrigation Science* 27(1): 11-23.

Ikerra, S. T., Semu, E. & Mrema, J. P. (2006). Combining Tithonia diversifolia and minjingu phosphate rock for improvement of P availability and maize grain yields on a chromic acrisol in Morogoro, Tanzania. *Nutrient Cycling in Agroecosystems* 76(2-3): 249-260.

Kadigi, R. M. J., Kashaigili, J. J. & Mdoe, N. S. (2004). The economics of irrigated paddy in Usangu Basin in Tanzania: water utilization, productivity, income and livelihood implications. *Physics and Chemistry of the Earth* 29(15-18): 1091-1100.

Kakengi, A. M., Shem, M. N., Mtengeti, E. P. & Otsyina, R. (2001). Leucaena leucocephala leaf meal as supplement to diet of glazing dairy cattle in semiarid Western Tanzania. *Agroforestry Systems* 52(1): 73-82.

Karachi, M. & Zengo, M. (1997). Legume forages from pigeon pea, leucaena and Sesbania as supplements to natural pastures for goat production in western Tanzania. *Agroforestry Systems* 39(1): 13-21.

Kimaro, A. A., Timmer, V. R., Chamshama, S. A. O., Mugasha, A. G. & Kimaro, D. A. (2008). Differential response to tree fallows in rotational woodlot systems in semi-arid Tanzania: Post-fallow maize yield, nutrient uptake, and soil nutrients. *Agriculture Ecosystems & Environment* 125(1-4): 73-83.

Kimaro, A. A., Timmer, V. R., Chamshama, S. A. O., Ngaga, Y. N. & Kimaro, D. A. (2009). Competition between maize and pigeonpea in semi-arid Tanzania: Effect on yields and nutrition of crops. *Agriculture Ecosystems & Environment* 134(1-2): 115-125.

Kullaya, I. K., Kilasara, M. & Aune, J. B. (1998). The potential of marejea (Crotalaria ochroleuca) as green manure in maize production in the Kilimanjaro region of Tanzania. *Soil Use and Management* 14(2): 117-118.

Laramee, J. & Davis, J. (2013). Economic and environmental impacts of domestic bio-digesters: Evidence from Arusha, Tanzania. *Energy for Sustainable Development* 17(3): 296-304.

Lemare, P. H. (1972). LONG-TERM EXPERIMENT ON SOIL FERTILITY AND COTTON YIELD IN TANZANIA. *Experimental Agriculture* 8(4): 299-&.

Lisuma, J. B., Semoka, J. M. R. & Semu, E. (2006). Maize yield response and nutrient uptake after micronutrient application on a volcanic soil. *Agronomy Journal* 98(2): 402-406.

Makoi, J. H. J. R. & Ndakidemi, P. A. (2007). Reclamation of sodic soils in northern Tanzania, using locally available organic and inorganic resources. *African Journal of Biotechnology* 6(16): 1926-1931.

Makurira, H., Savenije, H. H. G., Uhlenbrook, S., Rockstroem, J. & Senzanje, A. (2007). Towards a better understanding of water partitioning processes for improved smallholder rainfed agricultural systems: A case study of Makanya catchment, Tanzania. *Physics and Chemistry of the Earth* 32(15-18): 1082-1089.

Mbuligwe, S. E., Kassenga, G. R., Kaseva, M. E. & Chaggu, E. J. (2002). Potential and constraints of composting domestic solid waste in developing countries: findings from a pilot study in Dar es Salaam, Tanzania. *Resources Conservation and Recycling* 36(1): 45-59.

Mdangi, M., Mulungu, L. S., Massawe, A. W., Eiseb, S. J., Tutjavi, V., Kirsten, F., Mahlaba, T., Malebane, P., von Maltitz, E., Monadjem, A., Dlamini, N., Makundi, R. H. & Belmain, S. R. (2013). Assessment of rodent damage to stored maize (Zea mays L.) on smallholder farms in Tanzania. *International Journal of Pest Management* 59(1): 55-62.

Mdemu, M. V., Magayane, M. D., Lankford, B., Hatibu, N. & Kadigi, R. M. J. (2004). Conjoining rainfall and irrigation seasonality to enhance productivity of water in rice irrigated farms in the Upper Ruaha River Basin, Tanzania. *Physics and Chemistry of the Earth* 29(15-18): 1119-1124.

Mkoga, Z. J., Tumbo, S. D., Kihupi, N. & Semoka, J. (2010). Extrapolating effects of conservation tillage on yield, soil moisture and dry spell mitigation using simulation modelling. *Physics and Chemistry of the Earth* 35(13-14): 686-698.

Mligo, J. K. & Craufurd, P. Q. (2007). Productivity and optimum plant density of pigeonpea in different environments in Tanzania. *Journal of Agricultural Science* 145: 343-351.

Msangi, B. S. J., Bryant, M. J., Nkya, R. & Thorne, P. J. (2004). The effects of a short-term increase in supplementation on the reproduction performance in lactating crossbred dairy cows. *Tropical Animal Health and Production* 36(8): 775-787.

Msolla, M. M., Semoka, J. M. R. & Borggaard, O. K. (2005). Hard Minjingu phosphate rock: An alternative P source for maize production on acid soils in Tanzania. *Nutrient Cycling in Agroecosystems* 72(3): 299-308.

Mushi, D. E., Safari, J., Mtenga, L. A., Kifaro, G. C. & Eik, L. O. (2009). Effects of concentrate levels on fattening performance, carcass, and meat quality attributes of Small East African x Norwegian goats fed low quality grass hay. *Livestock Science* 124(1-3): 148-155.

Mushi, D. E., Safari, J., Mtenga, L. A., Kifaro, G. C. & Eik, L. O. (2009). Growth and distribution of non-carcass components of Small East African and F1 Norwegian crossbred goats under concentrate diets. *Livestock Science* 126(1-3): 80-86.

Mwakaje, A. G. (2008). Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints. *Renewable & Sustainable Energy Reviews* 12(8): 2240-2252.

Myaka, F. M., Sakala, W. D., Adu-Gyamfi, J. J., Kamalongo, D., Ngwira, A., Odgaard, R., Nielsen, N. E. & Hogh-Jensen, H. (2006). Yields and accumulations of N and P in farmer-managed intercrops of maize-pigeonpea in semi-arid Africa. *Plant and Soil* 285(1-2): 207-220.

Ndemanisho, E. E., Kimoro, B. N., Mtengeti, E. J. & Muhikambele, V. R. M. (2006). The potential of Albizia lebbeck as a supplementary feed for goats in tanzania. *Agroforestry Systems* 67(1): 85-91.

Okorio, J. & Maghembe, J. A. (1994). THE GROWTH AND YIELD OF ACACIA-ALBIDA INTERCROPPED WITH MAIZE (ZEA-MAYS) AND BEANS (PHASEOLUS-VULGARIS) AT MOROGORO, TANZANIA. *Forest Ecology and Management* 64(2-3): 183-190.

Pachpute, J. S. (2010). A package of water management practices for sustainable growth and improved production of vegetable crop in labour and water scarce Sub-Saharan Africa. *Agricultural Water Management* 97(9): 1251-1258.

Plazier, J. C. B., Nkya, R., Shem, M. N., Urio, N. A., & McBride, B. W. (1999). Supplementation of dairy cows with nitrogen molasses mineral blocks and molasses urea mix during the dry season. *Asian-Australasian Journal of Animal Sciences* 12(5): 735-741.

Raes, D., Kafiriti, E. M., Wellens, J., Deckers, J., Maertens, A., Mugogo, S., Dondeyne, S. & Descheemaeker, K. (2007). Can soil bunds increase the production of rain-fed lowland rice in south eastern Tanzania? *Agricultural Water Management* 89(3): 229-235.

Reyes, T., Quiroz, R., Luukkanen, O. & de Mendiburu, F. (2009). Spice crops agroforestry systems in the East Usambara Mountains, Tanzania: growth analysis. *Agroforestry*

Systems 76(3): 513-523.

Reyes, T., Quiroz, R. & Msikula, S. (2005). Socio-economic comparison between traditional and improved cultivation methods in agroforestry systems, East Usambara Mountains, Tanzania. *Environmental Management* 36(5): 682-690.

Rockstroem, J., Barron, J., Fox, P. (2002). Rainwater management for increased productivity among small-holder farmers in drought prone environments. *Physics and Chemistry of the Earth* 27(11-22): 949-959.

Rockstroem, J., Kaurnbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J. & Damgaard-Larsen, S. (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. *Soil & Tillage Research* 103(1): 23-32.

Rubanza, C. D. K., Shem, M. N., Bakengesa, S. S., Ichinohe, T. & Fujihara, T. (2007). Effects of Acacia nilotica, A-polyacantha and Leucaena leucocephala leaf meal supplementation on performance of Small East African goats fed native pasture hay basal forages. *Small Ruminant Research* 70(2-3): 165-173.

Rubanza, C. D. K., Shem, M. N., Otsyina, R. & Fujihara, T. (2005). Performance of Zebu steers grazing on western Tanzania native forages supplemented with Leucaena leucocephala leaf meal. *Agroforestry Systems* 65(3): 165-174.

Safari, J., Mushi, D. E., Mtenga, L. A., Kifaro, G. C. & Eik, L. O. (2011). Growth, carcass and meat quality characteristics of Small East African goats fed straw based diets. *Livestock Science* 135(2-3): 168-176.

Safari, J. G., Mushi, D. E., Mtenga, L. A., Kifaro, G. C. & Eik, L. O. (2011). Growth, carcass yield and meat quality attributes of Red Maasai sheep fed wheat straw-based diets. *Tropical Animal Health and Production* 43(1): 89-97.

Sarwatt, S. V. (1990). FEED-INTAKE, GROWTH-RATE AND DIGESTIBILITY COEFFICIENTS OF GROWING SHEEP FED HAY SUPPLEMENTED WITH CROTALARIA-OCHROLEUCA. *Animal Feed Science and Technology* 28(1-2): 51-59.

Sarwatt, S. V. (1992). EFFECTS OF REPLACING SUNFLOWER SEED CAKE WITH CROTALARIA-OCHROLEUCA HAY ON FEED-INTAKE, DIGESTIBILITY AND GROWTH-RATE OF GRAZING SHEEP. *Small Ruminant Research* 7(1): 21-28.

Sarwatt, S. V., Kapange, S. S. & Kakengi, A. M. V. (2002). Substituting sunflower seed-cake with Moringa oleifera leaves as a supplemental goat feed in Tanzania. *Agroforestry Systems* 56(3): 241-247.

Sekiya, N., Khatib, J. K., Makame, S. M., Tomitaka, M., Oizumi, N. & Araki, H. (2013). Performance of a Number of NERICA Cultivars in Zanzibar, Tanzania: Yield, Yield Components and Grain Quality. *Plant Production Science* 16(2): 141-153.

Shayo, C. M., Ogle, B. & Uden, P. (1997). Comparison of water melon (Citrullus vulgaris)-seed meal, Acacia tortilis pods and sunflower-seed cake supplements in central Tanzania .2. Effect on hay intake and milk yield and composition of Mpwapwa cows. *Tropical Grasslands* 31(2): 130-134.

Shem, M. N., Machibula, B. P., Sarwatt, S. V. & Fujihara, T. (2003). Gliricidia sepium as an alternative protein supplement to cottonseed cake for smallholder dairy cows fed on Napier grass in Tanzania. *Agroforestry Systems* 58(1): 65-72.

Shemdoe, R. S., Kikula, I. S., Van Damme, P. & Cornelis, W. M. (2009). Tillage Practices and Their Impacts on Soil Fertility in Farmer' Fields in Semi-Arid Central Tanzania. *Arid Land Research and Management* 23(2): 168-181.

Shemdoe, R. S., Van Damme, P. & Kikula, I. S. (2009). Increasing crop yield in water scarce environments using locally available materials: An experience from semi-arid areas in Mpwapwa District, central Tanzania. *Agricultural Water Management* 96(6): 963-968.

Sugihara, S., Funakawa, S., Kilasara, M. & Kosaki, T. (2010). Dynamics of microbial biomass nitrogen in relation to plant nitrogen uptake during the crop growth period in a dry tropical cropland in Tanzania. *Soil Science and Plant Nutrition* 56(1): 105-114.

Sugihara, S., Funakawa, S., Kilasara, M. & Kosaki, T. (2012). Effects of land management on CO2 flux and soil C stock in two Tanzanian croplands with contrasting soil texture. *Soil Biology & Biochemistry* 46: 1-9.

Szilas, C., Semoka, J. M. R. & Borggaard, O. K. (2007). Can local Minjingu phosphate rock replace superphosphate on acid soils in Tanzania? *Nutrient Cycling in Agroecosystems* 77(3): 257-268.

Tenge, A. J., De graaff, J. & Hella, J. P. (2005). Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania. *Applied Geography* 25(4): 348-366.

Vesterager, J. M., Nielsen, N. E. & Hogh-Jensen, H. (2007). Nitrogen budgets in crop sequences with or without phosphorus-fertilised cowpea in the maize-based cropping systems of semi-arid eastern Africa. *African Journal of Agricultural Research* 2(6): 261-268.

Vesterager, J. M., Nielsen, N. E. & Hogh-Jensen, H. (2008). Effects of cropping history and phosphorus source on yield and nitrogen fixation in sole and intercropped cowpea-maize systems. *Nutrient Cycling in Agroecosystems* 80(1): 61-73.

Wickama, J., Okoba, B. & Sterk, G. (2014). Effectiveness of sustainable land management measures in West Usambara highlands, Tanzania. *Catena* 118: 91-102.

Tanzania Grey Literature References

Angolile, B. (2004) Sun Drying Experimentation on Perforated Surfaces with Multiple Heights. A student special project submitted in partial fulfilment of the requirement for the degree of Bachelor of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania.

Bakengesa, S. Banzi, F.M. Mumba, M. and Maduka, S. (2002) Evaluation of the Potential of Rotational Woodlots in Improving Soil Fertility and Wood Production. AFRENA Annual Report- First Draft, HASHI/ICRAF Agroforestry Research Development Project, Ministry of Natural Resources and Tourism.

Evelius, V. (2012) Investigation of the Potential of Rooftop Rainwater Harvesting in Supplementing Domestic Water Supply in Morogoro Peri-Urban: A Case Study of Kingolwira Ward. A Student Special Project Submitted in Partial Fulfilment of the Requirement for the Degree of Bachelor of Science in Agricultural Engineering, Sokoine University of Agriculture, Morogoro, Tanzania.

Lumbani, M.G. (2006) Regulated Deficit Irrigation as a Water Management Strategy in Bean Production: A case Study of the Usangu Plains, Tanzania. A Student Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Irrigation Engineering and Management, Sokoine University of Agriculture, Morogoro, Tanzania.

Luoga, E. J and Bakengesa S (2004) Best Management Practices of Rotational Woodlots and Ngitili Systems in Shinyanga and Tabora regions, Tanzania. A draft consultancy report submitted to TAFORI, Morogoro, Tanzania.

Luswema, S.P. (1997) Performance of Rainwater Harvesting with Storage for Supplementary Irrigation for Paddy Production in Semi-Arid Hombolo, Tanzania. A Student Thesis

Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Agricultural Engineering, Sokoine University of Agriculture, Morogoro, Tanzania.

Mapara, L.P.T. (2002) The Use of Symbiotic Azolla-Caroliniana as Water Management Technique in Paddy Fields: A case study of Lower Moshi Irrigation Project in Tanzania. A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania

Mashinga, T.N. (1996) Adoption of Modified Pandey Bio-Economic Model for the Evaluating the Economic Feasibility of Rain Water Harvesting (RWH) for Supplementary Irrigation in Semi-Arid Areas of Tanzania. Dissertation Submitted in Partial Fulfilment for the degree of Master of Science in Agricultural Engineering, Sokoine University of Agriculture, Morogoro, Tanzania.

Mbiki, S. (1999) Socio-Economic Analysis of Rotational Woodlot System in Shinyanga, Tanzania. A Student Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Agricultural Economics, New Mexico State University, Las Cruses, New Mexico.

Mlengera, M. M (2013) Adaptation of cassava flash drying technology for smallholder farmers in Tanzania. A Dissertation submitted in partial fulfilment of the requirement for the degree of Master of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania.

Msafiri, M. (2008) Performance Evaluation and Management of Cassava Chipper and Cassava Crater. A Student Special Project Submitted in Partial Fulfilment of the requirements for the Degree of Bachelor of Science in Agricultural Engineering, Sokoine University of Agriculture, Morogoro, Tanzania.

Msafiri, R (2013) Design and Fabrication of a Centrifugal Sunflower Dehuller for Improved Sunflower Oil and Cake Quality. A Dissertation submitted in partial fulfilment of the requirement for the degree of Master of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania.

Munisi, A, I. M (2001) Establishment of a Digital Land Resources Database for Land Use Planning: A case study of Eastern Morogoro Rural District, Tanzania. A Dissertation submitted in partial fulfilment of the requirement for the degree of Master of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania.

Mwakabala, B. (2008) Potential Utilization of Rice Husks for Energy Production in Tanzania. A Student Special Project Submitted in Partial Fulfilment of the Requirement for the Degree of Bachelor of Science in Agricultural Engineering, Sokoine University of Agriculture, Morogoro, Tanzania.

Nindi, S. J (199) Comparative Evaluation of Soil Conservation Practices in Mbiga District: A Case Study of Tukuzi Village. A Dissertation submitted in partial fulfilment of the degree of Master of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania.

Nyanoka, E. (1995) Investigation of the Effect of Tillage Induced Condition on Soil Moisture Conservation in a Semi-Arid Environment. A dissertation submitted in partial fulfilment of the requirement for the degree of Master of Science in Agricultural Engineering of Sokoine University of Agriculture, Morogoro, Tanzania.

Otsyina, R and Asenga, D (1993a) Ngitili System and Its Implications on Agroforestry Technology Development in Sukumaland. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993b) Potential of Honey Production as a Value Added Product in Silvopastural System in Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993c) Evaluation of Sesbania Species and Provenances for Various Agroforestry Technologies in Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993d) Growth and Performance of Acacia Species Six Months after Planting at Lubaga, Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993e) Influence of Introduced and Local Multi-purpose Tree Species on Associated Maize Crop in a Mixed Intercropping System at Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993f) Potential of Acacia Polyacantha, Acacia Nolitica and Leucaena Leucocephala for Soil Fertility Improvement, Fodder and Fuel Wood in Rotational Woodlot Systems. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993g) Green Manure Decomposition for Acacia Tortilis, Acacia polyacangtha, Acacia nilotica and Leucaena leucocephala. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993h) Effects of Grazing Pressure on Fodder Production, Animal Weight Change and Regeneration of Fodder Reserve (Ngitiri). Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993i) Evaluation of Multi-purpose Trees on Rice Bunds for Mulch and Fodder Production. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993j) The Effects of Time and Amount of Luecaena Green Manure Application on Rainfed Floodland Rice Yields in Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania.

Otsyina, R and Asenga, D (1993k) Evaluation of the Influence of Luecaena and Gliricidia Manure on Striga Incidences in Sorghum on a Ferralic Cambisol. Tanzania ICRAF Agroforestry Projects Annual Report, Shinyanga, Tanzania..

Otsyina, R, Asenga, D and Mumba, M (1995a) Evaluation of Farmers Perception on Multi purpose Tree Species on Croplands. Tanzania ICRAF Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R, Asenga, D and Mumba, M (1995b) Evaluation of Browse Species for Fodder Production in Fodder Banks and Ngitiris, Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R, Asenga, D and Mumba, M (1995c) Performance Evaluation Acacia Species for Agroforestry Technologies in Shinyanga. Tanzania ICRAF Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R, Asenga, D and Mumba, M (1995d) Preliminary Evaluation of Various Multi purpose Tree Species for Live Fencing, Fodder and Wood Production. Tanzania ICRAF Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R, Asenga, D and Mumba, M (1995e) Evaluation of Various Multi-purpose Trees Intercropped with Maize. Tanzania ICRAF Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R, Asenga, D and Mumba, M (1995f) Potential of Neem Seed Powder for Controlling Maize Stalk Borers. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D and Mumba, M (1995f) Effects of Neem Seed Powder for Controlling Termites in Maize. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D and Mumba, M (1995g) Effects Leucaena Green Manures on Rainfed Lowland Rice Yields in Shinyanga. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D and Mumba, M (1995h) Evaluation of Multi-purpose Tree Species on Rice Bunds for Green Manure Production and Effects on Rice Yields. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D and Mumba, M (1995i) Potential of Acacia polyacantha, Acacia nilotica and Leucaena leucocephala for Soil Fertility Improvement, Fodder and Fuel wood in Rotational Woodlots Systems. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D and Mumba, M (1995j) On-farm Evaluation of Rotational Woodlots in Shinyanga. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D Makweta, A and Maduka, S (1997a) Evaluation of Four Multi-purpose Trees in Rotational Woodlots with Cotton. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D Makweta, A and Maduka, S (1997b) Performance Evaluation of Promising Live Fence Species for Ngitiri after one Year of Growth. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D Makweta, A and Maduka, S (1997c) Preliminary Performance Evaluation of Fodder Legumes in Improved Fallows. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D Makweta, A and Maduka, S (1997d) Effects of Tree Pruning Management on Maize Yield in the Post fallow Phase of Rotational Woodlot. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D Makweta, A and Maduka, S (1997e) Fodder Production in Rotational Woodlots. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D Makweta, A and Maduka, S (1997f) Early Performance of Leucaena Fodder Banks for Small scale Peri-Urban Dairies. ICRAF Tanzania Agroforestry Projects Annual Progress Report, Shinyanga, Tanzania.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998a) Competitive effects of some multi-purpose trees on Maize Yield and Soil

Nutrients. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998b) On-Farm Evaluation of Rotational Woodlots and Boundary Planting. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998c) Performance Evaluation of Lesser-known Leucaena Species and Provenances. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998d) Evaluation of Multi-purpose trees for Fodder Production in Fodder Banks. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998e) Evaluation of Fodder Banks for Small Scale Peri-Urban Dairy in Shinyanga. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998f). Effect of Rock Phosphate on Cotton Growth on a Vertic Soil. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998g). Effects of Fallow Species and Length on Soil Fertility and Cotton Yield Improvement on Sandy Loam Soil. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998h). Effects of Spacing and Rock Phosphate on the Performance of Gliricidia Seed Orchard. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bukengesa, S. Maduka, S. and Ngazi, H (1998i). Documenting Traditional Medicinal Plants and Practices in Shinyanga. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Otsyina, R Asenga, D. Ruvuga, S. Dery, B. Bakengesa, S. Maduka, S. and Ngazi, H (1998j). Identification of Factors that Influence the Adoption and Diffusion of Improved Wood Stove. Annual Report No. 125, HASHI/ICRAF Agroforestry Research Project, Shinyanga.

Ramadhani, S, (2008) Improvement of Manual Sunflower Extraction Machine. Student Special Project Submitted in Partial Fulfilment of the Requirement for the Degree of Bachelor of Science in Agricultural Engineering, Sokoine University of Agriculture, Morogoro, Tanzania.

Uganda Peer-Reviewed References

Abidin, P. E., van Eeuwijk, F. A., Stam, P., Struik, P. C., Malosetti, M., Mwanga, R. O. M., Odongo, B., Hermann, M. & Carey, E. E. (2005). Adaptation and stability analysis of sweet potato varieties for low-input systems in Uganda. *Plant Breeding* 124(5): 491-497.

Adkins, E., Tyler, E., Wang, J., Siriri, D. & Modi, V. (2010). Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. *Energy for Sustainable Development* 14(3): 172-185.

Alicai, T., Omongo, C. A., Maruthi, M. N., Hillocks, R. J., Baguma, Y., Kawuki, R., Bua, A., Otim-Nape, G. W. & Colvin, J. (2007). Re-emergence of cassava brown streak disease in Uganda. *Plant Disease* 91(1): 24-29.

Amoding, A., Tenywa, J. S., Ledin, S. & Otabbong, E. (2011). Effectiveness of crop-waste compost on a Eutric Ferralsol. *Journal of Plant Nutrition and Soil Science* 174(3): 430-436.

Buyinza, M., Senjonga, M. & Lusiba, B. (2010). Economic Valuation of a Tamarind (Tamarindus indica L.) Production System: Green Money from Drylands of Eastern Uganda. *Small-Scale Forestry* 9(3): 317-329.

Deal, C., Brewer, C. E., Brown, R. C., Okure, M. A. E. & Amoding, A. (2012). Comparison of kiln-derived and gasifier-derived biochars as soil amendments in the humid tropics. *Biomass & Bioenergy* 37: 161-168.

Dick, J., Skiba, U., Wilson, J. (2001). The effect of rainfall on NO and N2O emissions from Ugandan agroforest soils. *Phyton-Annales Rei Botanicae* 41(3): 73-80.

Ebregt, E., Struik, P. C., Odongo, B. & Abidin, P. E. (2007). Piecemeal versus one-time harvesting of sweet potato in north-eastern Uganda with special reference to pest damage. *Njas-Wageningen Journal of Life Sciences* 55(1): 75-92.

Fermont, A. M., Tittonell, P. A., Baguma, Y., Ntawuruhunga, P. & Giller, K. E. (2010). Towards understanding factors that govern fertilizer response in cassava: lessons from East Africa. *Nutrient Cycling in Agroecosystems* 86(1): 133-151.

Fischler, M. & Wortmann, C. S. (1999). Green manures for maize-bean systems in eastern Uganda: Agronomic performance and farmers' perceptions. *Agroforestry Systems* 47(1-3): 123-138.

Fischler, M., Wortmann, C. S. & Feil, B. (1999). Crotalaria (C-ochroleuca G Don) as a green manure in maize-bean cropping systems in Uganda. *Field Crops Research* 61(2): 97-107.

Kaizzi, C. K., Ssali, H. & Vlek, P. L. G. (2004). The potential of Velvet bean (Mucuna pruriens) and N fertilizers in maize production on contrasting soils and agro-ecological zones of East Uganda. *Nutrient Cycling in Agroecosystems* 68(1): 59-72.

Kaizzi, C. K., Ssali, H. & Vlek, P. L. G. (2006). Differential use and benefits of Velvet bean (Mucuna pruriens var. utilis) and N fertilizers in maize production in contrasting agro-ecological zones of E. Uganda. *Agricultural Systems* 88(1): 44-60.

Kaizzi, K. C., Byalebeka, J., Wortmann, C. S. & Mamo, M. (2007). Low input approaches for soil fertility management in semiarid eastern Uganda. *Agronomy Journal* 99(3): 847-853.

Karungi, J., Kyamanywa, S. & Ekbom, B. (2006). Estimating nitrogen needs of fresh market cabbage using a pre-side dress soil nitrate test (PSNT). *Annals of Applied Biology* 149(2): 103-109.

Kearney, S., Fonte, S. J., Salomon, A., Six, J. & Scow, K. M. (2012). Forty percent revenue increase by combining organic and mineral nutrient amendments in Ugandan smallholder market vegetable production. *Agronomy for Sustainable Development* 32(4): 831-839.

Lapenga, K. O., Ebong, C. & Opuda-Asibo, J. (2009). Effect of Feed Supplements on Weight Gain and Carcass Characteristics of Intact Male Mubende Goats Fed Elephant Grass (Pennisetum purpureum) ad libitum in Uganda. *Journal of Animal and Veterinary Advances* 8(10): 2004-2008.

Lapenga, K. O., Ebong, C. & Opuda-Asibo, J. (2009). Growth Performance and Feed Utilization by Intact Male Mubende Goats Fed Various Supplements with Elephant Grass (Pennisetum purpureum) as Basal Diet in Uganda. *Journal of Animal and Veterinary Advances* 8(10): 1999-2003.

Lapenga, K. O. & Rubaire-Akiiki, C. (2009). The Effect of Helminthiasis on Weight Gains and Carcass Values of Young Indigenous Goats in Uganda. *Journal of Animal and*

Veterinary Advances 8(10): 1993-1998.

Legg, J., Owor, B., Sseruwagi, P., Ndunguru, J. (2006). Cassava mosaic virus disease in East and Central Africa: Epidemiology and management of a regional pandemic. *Plant Virus Epidemiology* 67: 355-418.

McIntyre, B. D., Riha, S. J., Ong, C. K. (1997). Competition for water in a hedge-intercrop system. *Field Crops Research* 52(1-2): 151-160.

McIntyre, B. D., Speijer, P. R., Riha, S. J. & Kizito, F. (2000). Effects of mulching on biomass, nutrients, and soil water in banana inoculated with nematodes. *Agronomy Journal* 92(6): 1081-1085.

Mpairwe, D. R., Sabiiti, E. N. & Mugerwa, J. S. (1998). Effect of dried Gliricidia sepium leaf supplement on feed intake, digestibility and nitrogen retention in sheep fed dried KW4 elephant grass (Pennisetum purpureum) ad libitum. *Agroforestry Systems* 41(2): 139-150.

Mubiru, D. N. & Coyne, M. S. (2009). Legume Cover Crops are More Beneficial than Natural Fallows in Minimally Tilled Ugandan Soils. *Agronomy Journal* 101(3): 644-652.

Ngigi, S. N. (2003). What is the limit of up-scaling rainwater harvesting in a river basin? *Physics and Chemistry of the Earth* 28(20-27): 943-956.

Parker, A., Cruddas, P., Rowe, N., Carter, R. & Webster, J. (2013). Tank costs for domestic rainwater harvesting in East Africa. *Proceedings of the Institution of Civil Engineers-Water Management* 166(10): 536-545.

Sanginga, P. C., Kamugisha, R. N. & Martin, A. M. (2007). Conflicts management, social capital and adoption of agroforestry technologies: empirical findings from the highlands of southwestern Uganda. *Agroforestry Systems* 69(1): 67-76.

Siriri, D., Ong, C. K., Wilson, J., Boffa, J. M. & Black, C. R. (2010). Tree species and pruning regime affect crop yield on bench terraces in SW Uganda. *Agroforestry Systems* 78(1): 65-77.

Siriri, D., Wilson, J., Coe, R., Tenywa, M. M., Bekunda, M. A., Ong, C. K. & Black, C. R. (2013). Trees improve water storage and reduce soil evaporation in agroforestry systems on bench terraces in SW Uganda. *Agroforestry Systems* 87(1): 45-58.

Smit, N. (1997). The effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda. *Agriculture Ecosystems & Environment* 64(3): 191-

200.

Smithson, P. C., McIntyre, B. D., Gold, C. S., Ssali, H. & Kashaija, I. N. (2001). Nitrogen and potassium fertilizer vs. nematode and weevil effects on yield and foliar nutrient status of banana in Uganda. *Nutrient Cycling in Agroecosystems* 59(3): 239-250.

Smithson, P. C., McIntyre, B. D., Gold, C. S., Ssali, H., Night, G. & Okech, S. (2004). Potassium and magnesium fertilizers on banana in Uganda: yields, weevil damage, foliar nutrient status and DRIS analysis. *Nutrient Cycling in Agroecosystems* 69(1): 43-49.

Ssali, H., McIntyre, B. D., Gold, C. S., Kashaija, I. N. & Kizito, F. (2003). Effects of mulch and mineral fertilizer on crop, weevil and soil quality parameters in highland banana. *Nutrient Cycling in Agroecosystems* 65(2): 141-150.

Tibayungwa, F., Mugisha, J. Y. T. & Nabasirye, M. (2011). Modelling the effect of supplementing elephant grass with lablab and desmodium on weight gain of dairy heifers under stall-feeding system. *African Journal of Agricultural Research* 6(14): 3232-3239.

Tumwebaze, S. B., Bevilacqua, E., Briggs, R. & Volk, T. (2012). Soil organic carbon under a linear simultaneous agroforestry system in Uganda. *Agroforestry Systems* 84(1): 11-23.

van Asten, P. J. A., Wairegi, L. W. I., Mukasa, D. & Uringi, N. O. (2011). Agronomic and economic benefits of coffee-banana intercropping in Uganda's smallholder farming systems. *Agricultural Systems* 104(4): 326-334.

Wairegi, L. W. I. & van Asten, P. J. A. (2010). The agronomic and economic benefits of fertilizer and mulch use in highland banana systems in Uganda. *Agricultural Systems* 103(8): 543-550.

Wallmo, K. & Jacobson, S. K. (1998). A social and environmental evaluation of fuel-efficient cook-stoves and conservation in Uganda. *Environmental Conservation* 25(2): 99-108.

Wortmann, C. S. (2001). Nutrient dynamics in a climbing bean and sorghum crop rotation in the Central Africa Highlands. *Nutrient Cycling in Agroecosystems* 61(3): 267-272.

Wortmann, C. S. & Kaizzi, C. K. (1998). Nutrient balances and expected effects of alternative practices in farming systems of Uganda. *Agriculture Ecosystems & Environment* 71(1-3): 115-129.

Wortmann, C. S., McIntyre, B. D. & Kaizzi, C. K. (2000). Annual soil improving legumes: agronomic effectiveness, nutrient uptake, nitrogen fixation and water use. *Field*

Crops Research 68(1): 75-83.

Zake, J., Tenywa, J. S. & Kabi, F. (2010). Improvement of Manure Management for Crop Production in Central Uganda. *Journal of Sustainable Agriculture* 34(6): 595-617.

Uganda Grey Literature References

Abalo, G., Hakiza, J.J., Kakuhenzire, R.M., El-Bedewy, R. and Adipala, E. (2001). Agronomic performance of twelve elite potato genotypes in southwestern Uganda. *African Crop Science Journal* 9:17 -23.

Ajotu, B. (2013). Traditional management and effect of Borassus Aethiopum parklands on the growth and grain yield of finger millet in Soroti district. Unpublished MSc. thesis. Makerere University, Uganda.

Aluma, J., Okorio, J., Byenkya, S., Wajja-Musukwe, N., Muwanga, J. (1991). Upperstorey multipurpose tree (MPT) screening trials. AFRENA-Uganda Project No. 43

Anguria, P. (2000). Dry matter production and partitioning in sweet potato (*Impomoea batatus* (L.) Lam) under different soil fertility regimes.

Ayanga, W. (2011). Submission of sunflower candidate varieties for variety release.

Begumana, J. (1998). To what extent is biomass use sustainable in Tororo and Mubende? Unpublished MSc. thesis. Makerere University, Uganda.

Buyinza, J. (2014). Above-ground biomass and carbon stocks of different land cover types in Mt. Elgon, Eastern Uganda. Unpublished MSc. thesis. Makerere University, Uganda.

Ebanyat, P. (2009). A road to food: efficacy of nutrient management options targeted to heterogeneous soilscapes in the Teso farming system, Uganda. PhD. Thesis. Wageningen University UR, Wageningen, Netherlands.

Egeru, A. (2014). Climate Risk Management Information, Sources and Responses in a PastoralRegion in East Africa.

Egeru, A. (2014). CLIMATE CHANGE INDUCED VARIABILITY IN FORAGE PRODUCTION IN A SEMI ARID ECOSYSTEM IN NORTH EASTERN UGANDA. MSc. Thesis. University of Nairobi, Nairobi, Kenya.

Gabiri, G. (2013). CLIMBING AND BUSH BEANS' CULTIVATION EFFECTS ON RUNOFF, SOIL PROPERTIES AND SOIL AND NUTRIENT LOSSES IN BUFUNDI SUB CATCHMENT, UGANDA. MSc. Thesis. Kenyatta University, Nairobi, Kenya.

Gateese, T. (2011). The Impact of Rice growing on Wetlands and People's livelihoods: A case study of Semuto sub-county, Luwero District. Unpublished MSc. thesis. Makerere University, Uganda.

IFDC, 2014. Cost benefit analysis of Interventions.

Kaizzi, C.K. (1998). Effect of plant residues and other organic manures on the maintenance and improvement of soil fertility.

Kaizzi, C.K., & Ssekabembe, R. (1998). The effect of farm yard manure (FYM) and crop residue management on soil fertility and the yield of beans at the farm level.

Kamusingize, D. (2014) Carbon Sequestration Potential of East African Highland Cultivars in Uganda. Unpublished MSc. thesis. Makerere University, Uganda.

Katafiire, M. (2004). Management of bacterial wilt of potato using rotation crops in southwestern Uganda. Unpublished MSc. thesis. Makerere University, Uganda.

Katuromunda, S. (2001). Compatibility and productivity of forage legumes with maize and elephant grass in the peri-urban smallholder crop livestock production systems. Unpublished MSc. Thesis. Makerere University, Uganda

Kiconco, S. (2009). Carbon sequestration potential and community livelihood benefits of selectedon-farm indigneous trees species in Bitereko sub-county, Bushenyi district. Unpublished MSc. Thesis. Makerere University, Uganda

Kifumba, D. N. (2000). Natural tree regeneration and habitat structure in disturbed forest, Mount Elgon National park, Uganda: Implications for forest management. Unpublished MSc. Thesis. Makerere University, Uganda

Kiwanuka, A. (2008). A Comparative study of the potential of certified organic farming to improve soil, water resource management and incomes of small-scale farmers in Mityana district, Central Uganda. Unpublished MSc. Thesis. Makerere University, Uganda

Kyamanywa, S. Integrated management bean fly (*Ophiomyia sp.*) bean aphids (*Aphis fabae*) and flower thrips (*Megalurothrips sjostedti*) on common beans on small scale farms in Uganda

Majaliwa-Mwanjalolo, J. G. (1998). Effect of vegetation cover and biomass development on soil lossfrom maize based cropping systems. Unpublished MSc. Thesis. Makerere University, Uganda.

Makuma-Massa, H., Ochanda, D., Nandozi C., Musoba, E., Tusiime, C., Nasaka J., Owamanyi A., Kigaye E., Otage W. P., Bwogi A., Ntenge P., Egaru M., Sekisambu R., Mfutumikiza, D., Majaliwa, J.G.M. (). Land Use Change Effect on Carbon Stocks in Uganda Urban Areas: Case of Kabarole District

Makumbi, D. & Rubaihayo, P. R. (1994). Uganda highland banana germplasm evaluation. NARO, Uganda.

Male-Kayiwa, B.S., Ndawula, W., Kitinda, X., Mukabalanga, J., & Turyahabwa, C. ().Bean breeding

Mugabi, D. (2003). Abundance, population structure, distribution and socio-economic value of medicinal plant resources to the Tepeth community, Moroto district, Uganda. Unpublished MSc. Thesis. Makerere University, Uganda.

Muhwezi, A. M. (2012). Perception of and adaptation to climate change among agricultural communities of Kabarole District. Unpublished MSc. Thesis. Makerere University, Uganda.

Mwerea R. L. (2013). Climate change adaptation.

Namara, J. (2002). The abundance and distribution and community utilisation of *Loeseneriella apocynoides* and *Manilkara obovata* species in Sango Bay forest, Raaki district.

NARO. (1998). Animal production research programme

NARO. (1998). Integration of broom making and quality seed production of *Panicum maximum*

Niringye, C. (1998). Response of beans to hedgerows and prunnings of Calliandra (*Calliandra calothyrsus*) and Alnus (*Alnus acuminata*)

Nknonya, E., Pender, J., Jagger, P., Sserunkuuma, D., &Kaizzi, C. K. (2002). Strategies for Sustainable Livelihoods and Land Management in Uganda. Research report manuscript submitted to the IFPRI Publications Review Committee.

Nsengiyunva, M.M. (2013). The Impact of climate variability and change on sorghum yield in the Teso farming system

Nyombi, K., van Asten, P. J. A., Corbeels, M., Taulya G., & Giller, K. E. (2010). Mineral fertilizer response and nutrient use efficiencies of East African highland banana (*Musa ssp.*, AAA EAHB, cv. Kisansa). *Field Crops Research* 117(1): 38-50.

Ogwal, K. (). Effect of host reaction on epidemics of Asparagus rust disease in Uganda

Okech, S., Gold, C., Speijer, P., Ssali, H., Tushemereirwe, W. (1998). Soil fertility, soil conservation and banana weevil interactions in established banana fields in Ntugamo District

Okello, D.K. (2014). Registration of 'Serenut 5R' Groundnut.

Okello, D. K., Monyo, E., Deom C.M., Ininda, J., & Oloka, H. K. 2013. Groundnuts production guide for Uganda: Recommended practices for farmers. National Agricultural Research Organisation, Entebbe.

Okongo, L. R. B. (2011). The diversity and nutritional values of wild food plants of the Acholi subregion, Northern Uganda

Omamo, S. W. (2003). Fertilizer trade and pricing in Uganda. *Agrekon*, 42(4), 310-324.

Omiat, G., &Diiro, G. (2005).Rationalization and Harmonization of Fertilizer Policies, Laws, Regulations, and Procedures in Uganda. Report for the Eastern and Central Africa Programme for Agricultural Policy Analysis (ECAPAPA). Entebbe, Uganda: Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA).

Opio, F., Kyamanywa, S., Mugaga Isaac and Takusewanya, R., (1997). Management of root rots in Southwestern Uganda. In: National Beans Programme (UNBP) Annual Report 1996/97. Namulonge Agricultural and Animal Production Research Institute (NAARI), National Agricultural Research Organization (NARO), 62-69.

Opio, F.A., Mawejje, D. and Sekabembe, R., (1997). Integrated Disease management. In: Uganda National Bean Programme (UNBP) Annual Report 1996/97, Namulonge

Agricultural and Animal Production Research Institute (NAARI), National Agricultural Research organization (NARO), pp. 60-61.

Oyuko, S. (2013). *Vitellaria paradoxa* fruit production in the shea parklands of Otuke district, Northern Uganda

Ravnborg, H. M., Bashaasha, B., Pedersen, R. H., & Spichiger, R. (2013). Land tenure security and development in Uganda. DIIS.

SAARI. (2002). Development of and promotion of technologies for integrated management of Aphids on Cowpea in the Teso Farming System. NARO Annual Report 2002/2003

Sserunkuuma, D. (2005). The adoption and impact of improved maize and land management technologies in Uganda. *Electronic Journal of Agricultural and Development Economics*, 2(1), 67-84.

Sirike, J. (2012). Impact of land use/cover change on carbon stock dynamics and river water quality: A case study of River Atari Kapchorwa District. Unpublished MSc. Thesis. Makerere University, Uganda

Tukamuhabwa P., Mukabalanga, J., Kitinda, E., Ndaula, W., Eyedu, H., Takusewanya, R., Kabyi, P., Turyahabwa, C. (1998). Bean breeding. Namulonge Agricultural and Animal Production Research Institute (NAARI). Annual Report 1997/1998.

Tukamuhebwa, P., Namayanja, A., Mukabalanga, J., Kitinda, E., Eyedu, H., Takusewamya, R., Kabayi, P., & Turyahabwa, C. (2000). Bean breeding. Namulonge Agricultural and Animal Production Research Institute (NAARI). Annual Report 1999/2000.

Taulya, G. (2004). Topsoil depth-banana yield relationships on a chromic Luvisol in Lake Victoria basin microcatchment. Unpublished MSc. Thesis. Makerere University, Uganda

Twongyirwe, R. (2010). Dynamics of forest cover conversion in and around Bwindi Impenetrable Forest and impacts on Carbon stocks and soil properties. Unpublished MSc. Thesis. Makerere University, Uganda

Wafula, S. D. (2014). Impact of Climate change on agricultural production in a montane agroecological zone of Bufumbo sub-county, Mbale District, Eastern Uganda. Unpublished MSc. Thesis. Makerere University, Uganda

Wajja-Musukwe, N., Bamwerinde, W., Raussen, T., Siriri, D., Ayesiga, R., Gerrits, A., Mbalule, M. (1998). Wood Production Systems in the Kigezi Highlands: Boundary planting with *Grevillea*, *Alnus* and *Cedrela*

Wandera, A. S. (2000). Mapping and evaluation of polewood resources around Rwenzori Mountains National Park (RMNP) in western Uganda: a case study of Kazingo, Rubona and Kasulenge pilot parishes. Unpublished MSc. Thesis. Makerere University, Uganda

Zizinga, A. (2013). Viability analysis of climate change adaptation and coping practices for agriculture productivity in Rwenzori Region: Kasese District. Unpublished MSc. Thesis. Makerere University, Uganda

RESEARCH PROGRAM ON
Climate Change, Agriculture and Food Security

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic initiative of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT). CCAFS is the world's most comprehensive global research program to examine and address the critical interactions between climate change, agriculture and food security.

For more information, visit www.ccafs.cgiar.org

Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

CCAFS is led by:

Strategic partner:

Research supported by: