Integrated soil fertility management in eastern and western Africa: The role of knowledge and innovation systems, its adoption and impact

Dissertation for the acquisition of the academic degree
Doktor der Agrarwissenschaften (Dr. agr.)

Submitted to the Faculty of Organic Agricultural Sciences (FB11)
University of Kassel

Ivan Solomon Adolwa

Witzenhausen, January 2017

Integrated soil fertility management in eastern and western Africa: The role of knowledge and innovation systems, its adoption and impact

Dissertation for the acquisition of the academic degree
Doktor der Agrarwissenschaften (Dr. agr.)

Submitted to the Faculty of Organic Agricultural Sciences (FB11)
University of Kassel
(Fachbereich Ökologische Agrarwissenschaften, Universität Kassel)

Organic Plant Production and Agroecosystems
Research in the Tropics and Subtropics

Ivan Solomon Adolwa

Witzenhausen, January 2017

This work has been approved by the Faculty of Organic Agricultural Sciences of the University of Kassel as a thesis for acquiring the academic degree of Doktor der Agrarwissenschaften (Dr. agr.).

First Supervisor:	Prof. Dr. Andreas Buerkert, University of Kassel
Second Supervisor:	Dr. Stefan Schwarze, University of Goettingen
Examiner:	Prof. Dr. Nikolaus Schareika, University of Goettingen
Examiner:	Prof. Dr. Detlev Moeller, University of Kassel
Defense date:	January 25, 2017

Die vorliegende Arbeit wurde vom Fachbereich Ökologische Agrarwissenschaften der Universität Kassel als Dissertation zur Erlangung des akademischen Grades eines Doktor der Agrarwissenschaften (Dr. agr.) angenommen.

Erster Gutachter:	Prof. Dr. Andreas Buerkert, Universität Kassel
Zweiter Gutachter:	Dr. Stefan Schwarze, Georg-August-Universität Göttingen
Prüfer:	Prof. Dr. Nikolaus Schareika, Georg-August-Universität Göttingen
Prüfer:	Prof. Dr. Detlev Moeller, Universität Kassel
Tag der mündlichen Prüfung:	25.01.2017

Erklärung

„Hiermit versichere ich, dass ich die vorliegende Dissertation selbständig, ohne unerlaubte Hilfe Dritter angefertigt und andere als die in der Dissertation angegebenen Hilfsmittel nicht benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Dritte waren an der inhaltlichen Erstellung der Dissertation nicht beteiligt; insbesondere habe ich nicht die Hilfe eines kommerziellen Promotionsberaters in Anspruch genommen. Kein Teil dieser Arbeit ist in einem anderen Promotions- oder Habilitationsverfahren durch mich verwendet worden.“

Declaration

“I herewith give assurance that I completed this dissertation independently without prohibited assistance of third parties or aids other than those identified in this dissertation. All passages that are drawn from published or unpublished writings, either word-for-word or in paraphrase, have been clearly identified as such. Third parties were not involved in the drafting of the content of this dissertation; most specifically I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.”

Witzenhausen, ---

(Ivan Solomon Adolwa)

Preface

This Ph.D. study was partly funded by the Urban Food^{plus} project (FKZ: 031A242A) sponsored under the GlobE-Africa-Initiative by the German Federal Ministry of Education and Research (BMBF). The study was also funded through a German Academic Exchange Service (DAAD) scholarship. The research conducted focuses on the adoption and impacts of integrated soil fertility management and the role of knowledge and innovation systems in disseminating innovations. The first chapter introduces and contextualizes the entire study and outlines the framework for the research. Research gaps and questions are identified and the objectives stated.
Chapters two, three and four contain manuscripts in different stages of publication in international peer-reviewed journals.

Chapter two:

Adolwa, I.S., S. Schwarze, I. Bellwood-Howard, N. Schareika, and A. Buerkert. A comparative analysis of agricultural knowledge and innovation systems in Kenya and Ghana: Sustainable agricultural intensification in the rural-urban interface. *Agriculture and Human Values* (First Online, 7^{th} of October 2016). DOI:10.1007/s10460-016-9725-0

Chapter three:

Adolwa, I.S., S. Schwarze, B. Waswa, and A. Buerkert. Understanding system innovation adoption: A comparative analysis of integrated soil fertility management uptake in Tamale (Ghana) and Kakamega (Kenya). *Renewable Agriculture and Food Systems* (Under review, submitted on the 24^{th} of June 2016).

Chapter four:

Adolwa, I.S., S. Schwarze, and A. Buerkert. Impacts of integrated soil fertility management on yield and household income: The case of Tamale (Ghana) and Kakamega (Kenya). *Food Policy* (to be submitted).

Chapter five provides a detailed discussion of the various issues surrounding adoption and impacts of ISFM and how they are interlinked. This also includes a synopsis for scaling up and out and an articulation of the role of institutions in such processes. The chapter closes with policy implications and recommendations for various agricultural stakeholders and an outlook for future research.

Table of contents

List of tables

List of figures

List of acronyms

AE	Agronomic efficiency
AGR	African Green Revolution
AGRA	Alliance for a Green Revolution in Africa
AIS	Agricultural Innovation Systems
AKIS	Agricultural Knowledge and Innovation Systems
ANOVA	Analysis of variance
ATE	Average treatment effects
ATET	Average treatment effects on the treated
C	Carbon
CA	Conservation Agriculture
CBOs	Community-Based Organizations
CI	Conditional mean independence
CIAT	International Center for Tropical Agriculture
F	Fertilizer
GDP	Gross Domestic Product
ICT	Information Communication Technologies
INRM	Integrated Natural Resource Management
ISFM	Integrated Soil Fertility Management
IARC	International Agricultural Research Center
IG	Improved germplasm
KARLO	Kenya Agricultural Research and Livestock Organization
LA	Local adaptation
MIR	Mid infra-red
N	Nitrogen
NARS	National Agricultural Research Stations
N-AE	Agronomic efficiency of applied nitrogen fertilizer
NGOs	Non-Governmental Organizations
NIRS	Non-destructive infra-red spectroscopy
NRM	Natural Resource Management

OA	Organic amendment
OLS	Ordinary least squares
ORM	Ordinal regression model
UPA	Urban and peri-urban agriculture
UFP	Urban Food^{plus}
P	Phosphorus
PCA	Principal Component Analysis
POM	Potential outcome means
RAAKS	Rapid Appraisal of Agricultural Knowledge Systems
RMSEC	Root mean square errors of calibration
PSM	Propensity score matching
SARI	Savannah Agricultural Research Institute
SD	Standard deviation
SOC	Soil organic carbon
SOM	Soil organic matter
SNA	Social network analysis
SSA	Sub-Saharan Africa
SWT	Strength of weak ties
SRI	System of Rice IntensificSuation
TLU	Tropical livestock units

Acknowledgements

First of all, I thank Prof. Dr. Andreas Buerkert for according me the opportunity to conduct this study in his working group. I appreciate the faith he has bestowed in me throughout the entire course of my study. I also thank Dr. Stefan Schwarze for his scientific guidance. His constructive criticism and insightful comments have shaped this research. I also thank Prof. Dr. Nikolaus Schareika for his crucial input but most of all for his words of encouragement, which I will never forget. His guidance and advice particularly, during the initial phase of my fieldwork were quite profound. I am similarly indebted to Dr. Imogen Bellwood-Howard for her critical input especially for the first study. Her assistance during the early stages of my fieldwork, particularly the creation of linkages with agricultural stakeholders was critical. Our corporation on scholarly matters besides this study was also mutually beneficial.

This work would not have been possible without the assistance of partners, institutional employees, former colleagues, research assistants and farmers in Tamale and Kakamega. Starting with Tamale, I wish to thank Dr. Edward Yeboah (CSIR-Soil Research Institute) who was instrumental in my survey work. He kindly linked me with Dr. Wilson Dogbe and Mr. Edem (SARI) and Mr. Musah (MoFA) who helped me substantially. My research assistants namely Mr. Baba Akolga, Mr. Baba Alhassan and Mr. Mathias Anafu were with me every step of the way and without their dedication the survey would have been virtually impossible to conduct. I am grateful to Mr. Isaac Kofi and his friend Isaac who helped me with the preparation of soil samples for analysis. I also thank Mr. Prosper Amenuvor of SARI for help with soil analysis. I am very grateful to the hospitality accorded to me by Dr. Andre Bationo at his home before and after the tedious fieldwork sessions. His advice on a number of issues was very beneficial.

From the Kakamega side, I wish to thank Dr. Martins Odendo, Dr. Boaz Waswa, Dr. David Mbakaya and Mr. Patrick Oucho who facilitated my research work here and in some cases assisted me with equipment. They also linked me to relevant officials such as Ms. Adelide Muyembe, Shillen Muyanzi and Ms. Anne Murunga who aided me with logistics and background information. Mr. Solomon Lumasai and Mr. John Waswa were some of the contact farmers that were very helpful to me also in providing background information and logistics. I am grateful to my research assistants Ms. Sharon Kweyu, Mr. Nelson Farak, Mr. Frank Namwaya and Mr. Gideon Omito who were dedicated and very hardworking. I wish to thank laboratory assistants at KARLO for their help in soil preparation and pH analysis and also extend my thanks to Ms. Evonne Oyugi (CIAT) for her help in soil analysis and Mr. Andrew Sila and colleagues at ICRAF for their important work entailing infrared analysis. Of course, I cannot forget to thank the friendly and cooperative farmers and institutional actors that I interviewed at both study locations. This work is dedicated to them.

In addition, I extend thanks to my data entry clerks and many other people that have assisted me in other ways. I am thankful to Mrs. Ramadhan Mwanaima for her comments on sections of this thesis. Likewise, I am indebted to Dr. Michael Mgalula for his assistance with the maps and sincerely thank Dr. Sven Goenster-Jordan, Mr. Urban Lemp, Ms. Esther Mieves and Dr. Martin Wiehle for their help with translation of the summaries. My gratitude also goes to Dr. Volker Haering of UFP for logistical assistance and I would also like to thank Dr. Christoph Steiner for his help on UFP matters as well as translation. I am grateful to Ms. Sigrid Haber and Ms. Susanne Guenther for their help with administrative and financial issues, which eased my work.

I am also grateful to my friends and colleagues here in Witzenhausen and beyond for their moral support and encouragement. I am really glad to have shared wonderful and inspirational moments with Mrs. Ramadhan Mwanaima, Dr. Dora Neina, Ms. Jackie Ogolla, Dr. Michael Mgalula, Mr. Tichaona Muchemwa, Mr. Roba Guyo, Mr. Joseph Korese, Mr. Edmund Akoto-Danso, Dr. Takemore Chagomoka, Dr. Wario Hussein, Ms. Delphine Manka'abusi, Dr.Tobias Feldt, Ms. Sybille Faust and Ms. Greta Jordan.

Last but not least, I would like to thank my father, David Adolwa, mother, Janet Adolwa, and my brothers Justin Asige, Joe Akiruga and Dan Adolwa for their unyielding support, understanding and encouragement. I also thank my girlfriend Anne Munene for her patience, understanding, and love. Thanks also to God Almighty.

Summary

Africa's population is projected to double by 2050. This rise in population growth is placing enormous strain on the available resources to feed the populace and support livelihoods. This state of affairs is further exacerbated by nutrient mining, which is common in most farming systems in Sub-Saharan Africa (SSA). Hence, SSA remains the least productive region globally in terms of agricultural production. The yields of major cereals such as maize (*Zea mays* L.), which constitute a major staple for both rural and urban communities, are critically lower than in other regions. Against this backdrop, agricultural stakeholders including soil scientists, agronomist, social scientists, Non-Governmental Organizations (NGOs), extension agents, governments, and donors, have over the years developed a plethora of technologies to boost agricultural production. Nevertheless, the dissemination of these agricultural innovations and subsequent uptake by smallholder farmers has remained a challenge as evidenced by the persistently high yield gaps between farmers' fields and on-station trials.

Regrettably, Africa barely benefitted from the green revolution that has been lauded for the agricultural transformation in the tropics and sub-tropics. More recently, there have been renewed efforts by scientists and philanthropists to promote a uniquely African green revolution. This relatively new initiative adopted the Integrated Soil Fertility Management (ISFM) paradigm as a means to promote sustainable intensification of African farming systems. It also took into account the heterogeneity of African farming systems by prioritizing ISFM intervention areas according to agro-ecological and agro-economic zones. The moist savannah and woodland zone, within which northern Ghana and western Kenya are situated, is one such area. This is a maize belt of approximately 4.4 million km^2, with the potential size of land that can be put under maize production amounting to 32 million ha. The ISFM innovation combines the green revolution technologies and natural resource management (NRM) practices in new ways that may increase crop productivity while maintaining soil fertility. Several ISFM technologies were widely promoted in Tamale, northern Ghana starting from 2008 as well as in Kakamega, western Kenya from the early 2000s. However, as with other system innovations such as conservation agriculture (CA), uptake of the innovation has been dismally low and success cases are few and far between. There is a dearth of information on how effectively existing Agricultural Knowledge and Innovation Systems (AKIS) are disseminating ISFM to smallholder farmers. Plot level factors such as soil quality that may particularly influence ISFM adoption have also not been addressed in previous empirical studies. The effects of ISFM on yield and household income at the micro-level are largely unknown. Hence, this comparative study aimed at investigating a) whether there is a relationship between complete awareness of ISFM and its different components and formation of the various types of knowledge ties with AKIS actors, b) whether soil quality influences ISFM uptake by farmers, and c) whether ISFM adoption impacts maize yield and total household income. The specific objectives of the study were:

1) To assess the efficacy of agricultural knowledge and innovation systems in East (Kenya) and West (Ghana) Africa in the communication and dissemination of ISFM (Study I);

2) To investigate how specifically soil quality, and more broadly socio-economic status and institutional factors, influence farmer adoption of ISFM (Study II); and

3) To assess the effect of ISFM on maize yield and total household income of smallholder farmers (Study III).

To address these queries, AKIS actor interviews together with in-depth farmer interviews were applied for study I. A total of 25 actors representing 14 key formal organizations were interviewed in Tamale whereas 17 actors representing 15 key formal organizations were interviewed in Kakamega. Using this data, information flows between these actors were mapped using the Netdraw software package (UCINET 6.0). In addition, several network measures including betweenness were computed with the aid of the networking software UCINET 6.0 to reveal important information network characteristics. Further to this, a stratified random sampling approach was used to select 285 households in Tamale and 300 households in Kakamega. A structured questionnaire administered to the household heads or their representatives consisted of network questions to reveal the extent to which smallholder farmers exchanged agricultural information with both formal and informal actors. Subsequently, t-tests and one-way analysis of variance (ANOVA) were carried out to compare farmers' knowledge ties at different ISFM awareness levels. The structured questionnaire also contained sections on farm characteristics, crop production and management and the institutional context of agricultural production, which were utilized to answer the query pertaining to study II. Equally important, soil samples (0-20 cm depth) were drawn from 322 (Tamale, Ghana) and 459 (Kakamega, Kenya) maize plots belonging to the interviewed farmers. Laboratory analyses for soil organic carbon (SOC), total carbon (C), total nitrogen (N), available phosphorus (P), pH, and

soil texture (% clay, % sand, % silt) were subsequently conducted. Non-destructive infrared (NDIR) spectroscopy methods were employed for quick, fast and efficient analysis of the samples. Ordinal regression modeling using STATA 13 statistical package was applied in estimating the cumulative adoption of ISFM. Finally, study III was tackled using information on economic activities (including prices of inputs and outputs) obtained from the survey questionnaire. An economic analysis was carried out to assess costs and returns of maize production and was calculated at the plot level. In addition, total household annual income from different economic activities was computed. For this initial analysis, only mean comparisons between ISFM and non-ISFM plots or households were determined. To estimate causal effects of ISFM adoption, a counterfactual model was used to calculate the difference in outcomes (yield and household income) of the treatment (ISFM adoption).

Study I addressed the question of whether there was a relationship between farmers' knowledge of ISFM and ties to AKIS actors. The results showed that there was a positive relationship between complete ISFM awareness among farmers and weak knowledge ties to both formal and informal actors at both research locations. Moreover, farmers with more weak knowledge ties were more likely to know more ISFM components. Interestingly, the Kakamega AKIS revealed a relationship between complete ISFM awareness among farmers and them having strong knowledge ties to formal actors. The major implication of this finding is that further integration of formal actors with farmers' local knowledge seems to be crucial for the agricultural development progress in Tamale. This is because the knowledge system functions best in fostering learning of ISFM where there are adequate weak and strong ties between disparate actors.

Study II examined whether soil quality is crucial for ISFM adoption. According to model estimates, soil carbon seemed to preclude farmers from intensifying input use in Tamale, whereas in Kakamega it spurred complete adoption. A unit increase in total C increased the probability of non-adoption by 11.3%, whereas in Kakamega a unit increase in SOC increased the chances of complete adoption by 27.8%. This varied response by farmers to soil quality conditions is multifaceted. From the Tamale perspective, it is consistent with farmers' tendency to judiciously allocate scarce resources. Viewed from the Kakamega perspective, it points to a need for farmers here to intensify agricultural production in order to foster food security. In Kakamega, farmers with more acidic soils were more likely to adopt ISFM. A decrease in one

unit of pH was likely to increase use of improved germplasm and fertilizer by 13.6%. Other household and farm-level factors necessary for ISFM adoption included off-farm income, livestock ownership, farmer associations, and market inter-linkages. While the promotion of alternative organic amendments to boost soil fertility and correct acidity is important, emphasis should also be placed on increasing farmer access to credit. This may allow them to more easily apply the full set of ISFM practices across their fields.

Study III sought to address impacts of ISFM adoption on maize yield and total household income. Adoption of ISFM was found to contribute to yield increase in both Tamale and Kakamega. The average treatment effects on the treated (ATET) estimates revealed a yield gain of 16% for ISFM adopters at both locations. The innovation affected total household income only in Tamale, where ISFM adopters had an income gain of 20%. Farmers in Kakamega may not have realized income benefits due to high costs of inputs. Conversely, their counterparts in Tamale had received a 50% subsidy on fertilizers reducing the financial burden. Thus it was shown that different policy contexts can lead to divergent outcomes from innovation uptake.

The general discussion synthesized the three studies further detailing the inter-linkages between the various scales of ISFM adoption. Key issues discussed include those touching on broader institutional aspects that have implications on the scaling up and out of ISFM, the opportunities and tradeoffs that exist in farming systems, and ethnopedological factors that underlie management systems. Insights from additional data were drawn upon to substantiate the discussion. The main recommendations underscored the need to: (1) improve the functioning of AKIS, (2) enhance farmer access to hybrid maize seed and credit, (3) and conduct additional multi-locational studies as farmers operate under varying contexts.

Zusammenfassung

Die Bevölkerung Afrikas wird sich bis 2050 voraussichtlich verdoppeln. Dieser enorme Bevölkerungszuwachs strapaziert die verfügbaren Ressourcen, die für eine nachhaltige Ernährung der Bevölkerung und zur Existenzsicherung genutzt werden können. Die Situation wird weiter verschärft durch den Verlust der Bodenfruchtbarkeit, was in den meisten landwirtschaftlichen Systemen im subsaharischen Afrika (SSA) beobachtet wird. Dadurch bleibt SSA die Region mit der geringsten landwirtschaftlichen Produktivität weltweit. Die Erträge von wichtigen Getreidearten wie Mais (*Zea mays* L.), die das Hauptnahrungsmittel sowohl für ländliche als auch für städtische Gemeinden darstellen, sind wesentlich geringer als in anderen Regionen. Vor diesem Hintergrund haben landwirtschaftliche Akteure wie Bodenkundler, Agrarwissenschaftler, Sozialwissenschaftler, Nicht-Regierungs-Organisationen (NGOs), Beratungsstellen, Regierungen und Geldgeber eine Vielzahl an Technologien entwickelt, um die landwirtschaftliche Produktion zu steigern. Dennoch ist die Verbreitung dieser landwirtschaftlichen Innovationen und deren Umsetzung von Kleinbauern eine Herausforderung geblieben, wie die nach wie vor hohen Ertragsunterschiede zwischen bäuerlichen Feldern und Versuchsstationen zeigen.

Leider hatte Afrika von der grünen Revolution bis heute nicht profitiert. Eine relativ neue Initiative setzte sich das Paradigma des integrierten Bodenfruchtbarkeitsmanagements (ISFM) als Grundlage, um eine nachhaltige Intensivierung afrikanischer Landwirtschaftssysteme zu fördern. Es berücksichtigte außerdem die Heterogenität der landwirtschaftlichen Anbausysteme in Afrika, indem die Standorte für Demonstrationsprojekte des ISFM entsprechend agro-ökologischer und agro-ökonomischer Zonen ausgewählt wurden. Ein solcher Standort befindet sich in der feuchten Savannen- und Waldregion Nord-Ghanas und West-Kenias. Diese Region ist der sogenannte Maisgürtel mit einer Fläche von ca. 4,4 Mio. km², wobei die potentielle Maisanbaufläche bis zu 32 Mio. ha groß ist. Die Innovation des ISFM kombiniert die Technologien der grünen Revolution sowie die Nutzung natürlicher Ressourcen (NRM) auf neuartige Weise. Ziel ist die Ernte bei gleichzeitigem Erhalt der Bodenfruchtbarkeit zu steigern. Seit 2008 wurden verschiedene ISFM Technologien in Tamale, Nord-Ghana gefördert. Das hat in Kakamega, West-Kenia, bereits einige Jahre früher begonnen. Wie bei vielen anderen Innovationen, war die Akzeptanz allerdings kläglich gering und eine erfolgreiche Umsetzung blieb die Ausnahme. Dies lag nicht zuletzt daran, dass das Wissen, wie landwirtschaftliche

Expertise- und Innovationssysteme (AKIS) ISFM-Maßnahmen an Kleinbauern vermitteln können, unzureichend ist.

Flächendaten wie z.B. Bodenqualität, welche die Akzeptanz von ISFM beeinflussen könnten, wurden in früheren empirischen Studien nicht berücksichtigt. Der Einfluss von ISFM auf Erträge und Haushaltseinkommen auf dem Mikro-Level sind weitgehend unbekannt. Daher hatte diese Vergleichsstudie die Untersuchungen zum Ziel,

a) ob ein Zusammenhang zwischen einem vollständigen Bewusstsein von ISFM und seinen verschiedenen Aspekten und der Entstehung von diversen Verbindungen in Bezug auf Wissen mit AKIS-Akteuren existiert

b) ob die Bodenqualität die Annahme von ISFM durch Bauern beeinflusst,

c) ob die Annahme von ISFM einen Einfluss auf Maisertrag und das gesamte Haushaltseinkommen hat.

Die spezifischen Ziele der Studie waren:

1) Die Wirksamkeit der landwirtschaftlichen Wissens- und Innovationssysteme (AKIS) in Ost- (Kenia) und Westafrika (Ghana) bezüglich der Kommunikation und Verbreitung von ISFM zu beurteilen (Studie I);
2) Den Einfluss der Bodenqualität, des sozio-ökonomischen Status und der institutionellen Faktoren bezüglich der Annahme von ISFM durch Bauern zu bestimmen (Studie II); und
3) Den Einfluss von ISFM auf den Maisertrag und das Gesamthaushaltseinkommen von Kleinbauern zu bewerten (Studie III).

Um diesen Fragen nachzugehen, wurden für Studie I Interviews mit AKIS-Akteuren und detaillierte Interviews mit Bauern durchgeführt. In Tamale wurden insgesamt 25 Akteure als Vertreter von 14 Schlüsselorganisation befragt, während in Kakamega 17 Akteure als Vertreter von 15 Schlüsselorganisationen interviewt wurden. Auf Grundlage dieser Daten wurden unter Zuhilfenahme der Networking Software „Netdraw software package (UCINET 6.0)“ Informationsflüsse zwischen den zuvor genannten Akteuren grafisch dargestellt. Außerdem wurden mehrere Maßnahmen der Netzwerke, einschließlich „betweenness“, mit Hilfe der software abgebildet, um einige wichtige Charakteristika des Netzwerkes offenzulegen. Zudem wurde mittels einer stratifizierten Probennahme 285 Haushalte in Tamale und 300 Haushalte in

Kakamega ausgewählt. Ein strukturierter Fragebogen zum Netzwerk wurde mit Haushaltsvorständen bzw. ihren Vertretern durchgegangen und sollte offenlegen, wie Kleinbauern landwirtschaftliche Information über formelle als auch informelle Akteure austauschen. Anschließend wurden t-tests und Varianzanalysen (ANOVA) durchgeführt, um das Wissen von Bauern auf unterschiedlichen Kenntnissebenen bzgl. ISFM zu vergleichen. Der strukturierte Fragebogen enthielt außerdem einen Fragekatalog zu betrieblichen Merkmalen wie, Feldfrüchte und deren Management sowie zum institutionellen Zusammenhang der landwirtschaftlichen Produktion. Diese Daten wurden für die Studie II genutzt.

Zusätzlich wurden Bodenproben (0-20 cm Bodentiefe) auf 322 (Tamale, Ghana) und 459 (Kakamega, Kenia) Maisparzellen genommen, die von den befragten Bauern bewirtschaftet wurden. Diese wurden anschließend im Labor auf organischen Kohlenstoff (SOC), Gesamt-Kohlenstoff (C), Gesamt-Stickstoff (N), verfügbares Phosphat (P), pH und Bodentextur (% Ton, % Sand, % Schluff) analysiert. Ordinale Regressionsmodelle wurden mit der Statistiksoftware STATA 13 durchgeführt, um den Fortschritt bei der Annahme von ISFM abzuschätzen.

Für die Studie III wurde eine ökonomische Analyse durchgeführt, um Kosten und Erlöse der Maisproduktion zu bewerten. Diese wurde auf Flächenniveau berechnet. Zusätzlich wurde das gesamte Jahreshaushaltseinkommen aus verschiedenen wirtschaftlichen Aktivitäten ermittelt. Für diese anfängliche Analyse wurden ausschließlich Vergleiche der Mittelwerte zwischen ISFM- und Non-ISFM-Parzellen oder –Haushalten angestellt. Um kausale Effekte der Annahme von ISFM zu bewerten, wurde ein kontrafaktisches Modell zur Berechnung von unterschiedlichen Auswirkungen (d.h. in Ertrag oder Einkommen) einer ISFM-Annahme benutzt.

Studie I ging der Frage nach, ob eine Beziehung zwischen dem Wissen von Bauern über ISFM und Verbindungen zu AKIS-Akteuren besteht. Die Ergebnisse zeigten, dass es eine positive Korrelation zwischen vollständiger ISFM-Kenntnis bei Bauern und schwachen Wissens-Verbindungen sowohl zu formellen als auch zu informellen Akteuren an beiden Forschungs-Standorten gibt. Des Weiteren hatten Bauern mit schwächeren Wissens-Verbindungen mit größerer Wahrscheinlichkeit ein Wissen über eine höhere Anzahl an ISFM-Komponenten. Interessanterweise zeigte sich bei AKIS Kakamega einZusammenhang zwischen vollständiger ISFM-Kenntnis bei Bauern und starken Wissens-Verbindungen zu formellen Akteuren. Daraus kann man ableiten, dass eine weitere Integration von formellen Akteuren mit dem lokalen

Wissen von Bauern für den landwirtschaftlichen Entwicklungsprozess in Tamale entscheidend zu sein scheint. Der Grund hierfür ist, dass das Wissenssystem am besten funktioniert, wenn das Lernen von ISFM dort gefördert wird, wo adäquate schwache und starke Verbindungen zwischen ungleichen Akteuren existieren.

Studie II untersuchte, ob die Bodenqualität entscheidend ist für die Annhame von ISFM. Modell-Abschätzungen scheinen den Schluss zu erlauben, dass Kohlenstoff im Boden Bauern in Tamale von einer Intensivierung abhielt, während er in Kakamega eine vollständige Annahme anregte. Der Anstieg von Gesamt-Kohlenstoff um eine Einheit (zum Beispiel von 0.74 % auf 1.74 % Total C) erhöhte die Wahrscheinlichkeit einer Nicht-Annahme um 11.3 %, während in Kakamega ein Anstieg um eine Einheit SOC die Wahrscheinlichkeit einer vollständigen Annahme um 27.8 % erhöhte. Diese unterschiedliche Reaktion von Bauern auf die Bodenqualität ist facettenreich. Aus der Perspektive von Tamale-, geht dies einher mit der Neigung der Bauern, knappe Ressourcen angemessen zu verwenden. Betrachtet man die Situation aus Sicht Kakamegas, so weist sie auf eine Notwendigkeit für die hiesigen Bauern hin, die landwirtschaftliche Produktion zugunsten der Ernährungssicherheit zu intensivieren. In Kakamega nahmen Bauern mit stark sauren Böden ISFM mit höherer Wahrscheinlichkeit an. Die Abnahme des pH-Wertes um eine Einheit erhöhte die Wahrscheinlichkeit der Verwendung von verbessertem Samenmaterial und Dünger um 13.6 %. Weitere Faktoren auf Hof- und Haushaltslevel, die für eine Annahme von ISFM nötig sind, umfassen Einkommen außerhalb der Farm, Besitz von Vieh, bäuerliche Zusammenschlüsse und Zugang zu Märkten. Während einerseits die Förderung von alternativen organischen Zuschlagstoffen für eine Steigerung der Bodenfruchtbarkeit wichtig ist, sollte auch ein Schwerpunkt auf einen verbesserten Kreditzugang für Bauern gelegt werden. Dies würde Bauern die Möglichkeit geben, ein erweitertes Spektrum der ISFM-Praktiken auf ihren Feldern anzuwenden.

Studie III befasste sich mit Einflüssen einer ISFM-Annahme auf den Maisertrag und das Gesamthaushaltseinkommen. Die Annahme von ISFM erhöhte den Ertrag sowohl in Tamale als auch in Kakamega. Der durchschnittliche Behandlungseffekt auf die behandelten Varianten (ATET) offenbarte einen Ertragszuwachs von 16 % für ISFM-Anwender an beiden Standorten. Die Innovationen hatten lediglich in Tamale einen Einfluss auf das Gesamthaushaltseinkommen, wo ISFM-Anwender einen Einkommenszuwachs von 20% aufwiesen. Die Bauern in Kakamega konnten Einkommensverbesserungen aufgrund der hohen Input-Kosten nicht realisieren.

Düngemittel sind in Tamale subventioniert (50%), was die finanzielle Belastung mildert. Dies machte deutlich, dass verschiedene politische Kontexte zu Unterschieden in der Annahme von Innovationen führen können.

Die allgemeine Diskussion führte die drei Studien zusammen, indem sie die Verknüpfungen zwischen den verschiedenen Skalen der Anwendung von ISFM detailliert aufzeigt. Die diskutierten Kernpunkte umfassen Themenkomplexe zu weitergehenden institutionellen Aspekten, welche Auswirkungen auf das Hoch- und Runterskalieren von ISFM haben, Möglichkeiten und Zielkonflikte innerhalb landwirtschaftlicher Systeme als auch ethnopedologischen Faktoren, welche Bewirtschaftungssystemen zu Grunde liegen. Erkenntnisse, die aus zusätzlichen Daten gewonnen wurden, wurden genutzt, um die Diskussion zu substantiieren. Die wichtigsten Empfehlungen betonen die Notwendigkeit, die Funktionsfähigkeit von AKIS zu verbessern, den Zugang für Bauern zu Hybridmais und Krediten zu erhöhen und weitere Studien an mehreren Orten durchzuführen.

1 General introduction

1.1 Background

Agriculture continues to be a major contributor to the growth of most African economies. On average, this sector makes up 14% of the gross domestic product (GDP) and 28% of the working population are employed by public or private firms engaged in agriculture (FAO 2015). Although global agricultural production has grown dramatically over the past five decades, Sub-Saharan Africa (SSA) seems to have been left behind (World Bank 2007; FAO 2015). Cereal yields, for instance, were much higher in most other regions including Asia and the Americas than in Africa and have been on a steeper increase since 2000 (Figure 1).

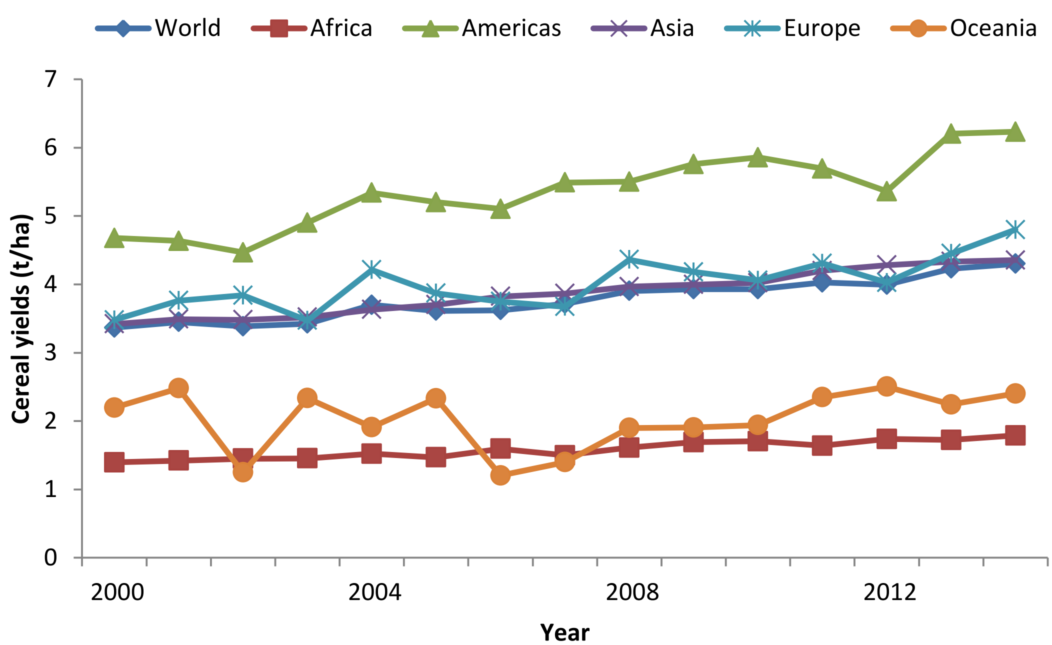

Figure 1 Cereal yield trends in different regions (Source: FAOSTAT 2015).

These data support the prevailing view that agriculture in Africa is lagging behind the rest of the world. In Ghana the agricultural sector constitutes 21% of the GDP and in Kenya 30% (FAO 2015). About 42% of the labor force is employed in the agricultural sector in Ghana whereas this figure is with 61% considerably higher in Kenya (FAO 2015). Nevertheless, both countries are among the breadbasket regions of the African continent (Figure 2). The northern part of Ghana and western Kenya lie in the moist savanna and woodland zone that includes the Guinea Savanna of West Africa, East Africa's Highland Mosaic and Miombo Woodlands of southern Africa, which are suitable for maize-grain legume cropping systems (Sanginga and Woomer 2009). In Ghana, the food crops that constitute the largest share of the dietary energy supply are starchy roots (40%), closely followed by cereals (26%), then oil crops (4.2%) and vegetables (0.9%) (FAO 2015). However, in Kenya, the food crops with largest dietary energy supply are cereals (46%) followed by starchy roots (10%), pulses (6%) and vegetables (1.4%; FAO 2014). Among the cereals, maize is the most important staple food of the local communities in both countries, particularly in the northern region of Ghana and western part of Kenya (Odendo et al. 2007; Chagomoka et al. 2016).

Agricultural production in SSA has been greatly constrained by biophysical, socio-economic and politico–institutional factors. It is widely known that West Africa's soils are characterized by inherent low soil fertility as they did not benefit from volcanic or glacial rejuvenation and have been continually subjected to nutrient mining. This problem is aggravated by low fertilizer use, the lowest of all the continents (Bationo et al. 2012; Vanlauwe et al. 2014a), which poses a serious threat to the millions of smallholder farmers who depend on agriculture for sustenance and as a source of livelihood. Consequently, agricultural stakeholders ranging from national and international research centers to donors have for decades promoted soil fertility innovations to bring about a green revolution for Africa. The Alliance for a Green Revolution in Africa (AGRA) is one among the many organizations at the forefront of this initiative. Integrated Soil Fertility Management (ISFM) is the paradigm that was adopted by AGRA about ten years ago to help alleviate soil fertility constraints and boost agricultural production. ISFM has for some time now been recognized as one of the suitable means for soil fertility improvement in Africa (Kessler et al. 2016). Nevertheless, the wide-scale adoption of ISFM and other similar innovations has been minimal thus hardly any impact has been realized beyond the plot level (Andersson and D'Souza 2014; Kessler et al. 2016). This situation has persisted despite the presence of Agricultural Knowledge and Innovation Systems (AKIS), encompassing diverse actors and their interactions and linkages, through which these innovations can be disseminated.

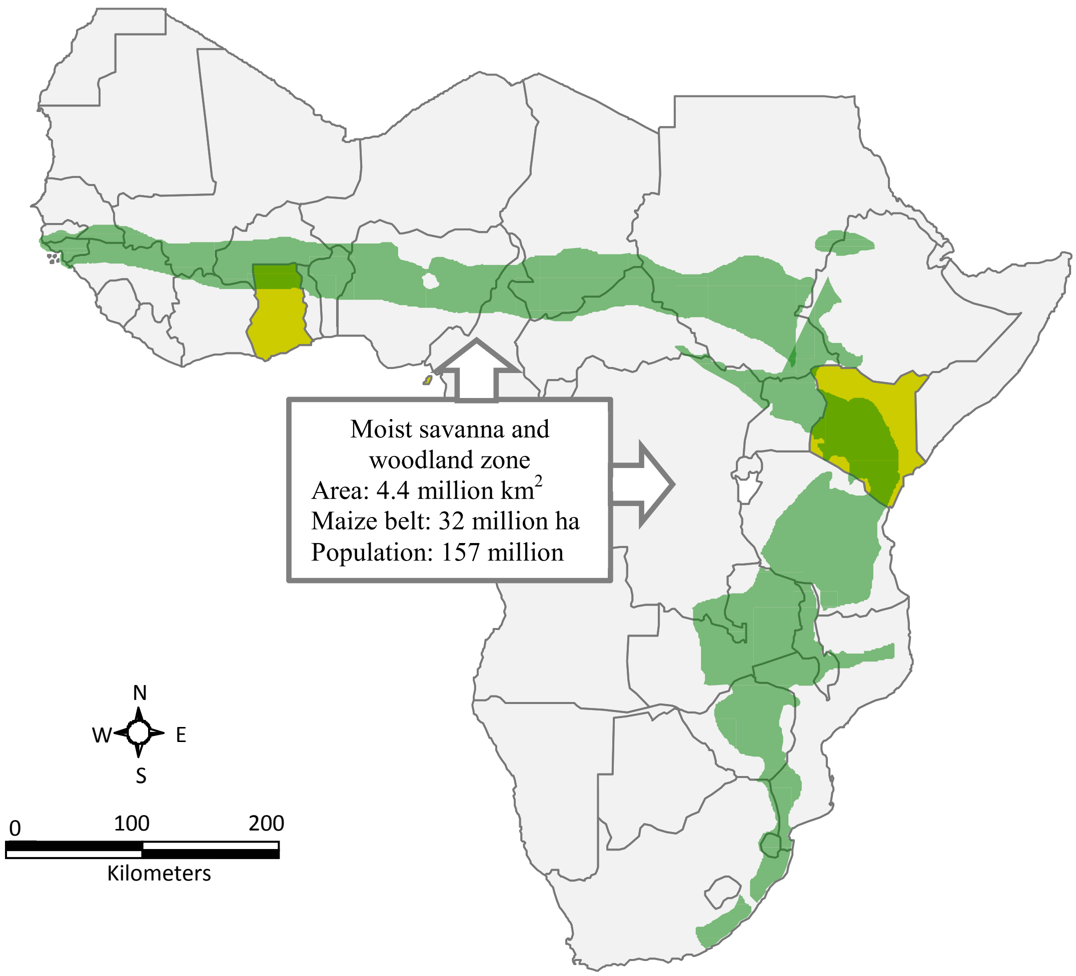

Figure 2 The moist savannah and woodland zones of Sub-Saharan Africa (adapted from Sanginga and Woomer 2009).

1.2 Soil fertility innovations: ISFM in context

One of the system innovations proposed to tackle constraints to sustainable intensification in Africa is ISFM. Other relevant innovations in this regard include conservation agriculture (CA), the system for rice intensification (SRI) and agroforestry. ISFM is defined as a set of soil fertility management practices that entail the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions to maximize agronomic use efficiency of the applied nutrients and improve crop productivity (Vanlauwe et al. 2010; Bationo and Waswa 2011). As ISFM is holistic, it also considers socio-economic aspects such as input-output markets, access to credit and value-chain approaches (Bationo and Waswa

2011). The ISFM paradigm became crystallized at the turn of the millennium with a new emphasis on improving the use efficiency of inorganic and organic fertilizer combinations while adapting nutrient management strategies to local conditions (Bationo and Waswa 2011; Kolawole 2013). This followed a shift in soil fertility management paradigms starting with the external input paradigm, which was instigated with the success of the 'Green Revolution' in the 1960s and 1970s, to the low-input sustainable agriculture (LISA), which in turn evolved into integrated nutrient management (INM) and integrated nutrient resource management (INRM) concepts (Vanlauwe 2004; Bationo and Waswa 2011). ISFM has in recent discussions been proposed as a fourth principle of CA, with a linkage being made between crop productivity and crop residues, which are an important component of CA (Vanlauwe et al. 2014b).

Thus the central tenets of the ISFM paradigm encompass on-farm recycling of nutrients, efficient use of nutrients to reduce their losses to the environment, making use of local, traditional and scientific knowledge, and integrating these into technologies that enable sustainable soil fertility management (Vanlauwe 2004; Tittonell et al. 2008). Some soil fertility technologies that have been developed and disseminated in western Kenya and northern Ghana include crop residue management, mineral fertilizers, improved germplasm, composting and green manures (Figure 3). The major idea behind ISFM is based on the combination of these available technologies in a way that not only preserves soil quality but also increases its productivity (Sanginga and Woomer 2009). As ISFM is knowledge-intensive, information transfer and extension services are crucial.

1.3 Agricultural extension approaches: The emergence and evolution of AKIS

The approaches utilized in the transfer of agricultural innovations have evolved considerably over the past 50 years. These have culminated in the most recent approach, which is referred to as AKIS. An AKIS is composed of producer organizations such as farmer associations or cooperatives and both public (agricultural research, extension and training, and regulatory service institutions) and private (non-governmental organizations, input suppliers and marketers) agricultural service providers, the knowledge flows that characterize interactions between them and the institutions that govern how they interact (Rees et al. 2000; Probst et al. 2012).

Table 1 summarizes the evolution of AKIS from linear models of knowledge transfer to multi-actor systems. The concepts of agricultural knowledge and information systems and Agricultural

Innovation Systems (AIS) have been recently merged into Agricultural Knowledge and Innovation Systems (AKIS), more so in the European Union policy and research context (Klerkx et al. 2012).

Figure 3 A range of ISFM technologies in Tamale and Kakamega that include (A) biochar and compost, (B) stake composting, (C) crop residue management, and (D) farmyard manure.

Rapid Appraisal of Agricultural Knowledge Systems (RAAKS), Participatory Rural Appraisal (PRA), and Strengths, Weaknesses Opportunities and Threats Analysis (SWOT) are some of qualitative methodologies that have been applied in investigating agricultural information and knowledge systems (Rees et al. 2000; Hulsebosch 2001; Munyua and Stilwell 2010; van Mierlo et al. 2013). However, these methodologies do not furnish a suitable means for hypothesis testing given the "soft methodology" nature of their approaches. The complexity of interactions within social systems such as AKIS has led to the development of methodologies useful in quantitatively assessing these systems. Social network analysis (SNA) is one such methodology that is most often used to elicit, visualize, and analyze social relations among multiple actors and social networks (Isaac et al. 2007; Spielman et al. 2009b). Whereas conventional data tend to focus on the attribute of actors, SNA focuses on patterns of relations between actors. In which case the unit of analysis is the “dyad pair of entities” as proposed by Spielman et al. (2009a) or socio-ecological systems (SES) motifs from the socio-ecological perspective of Bodin and Tengö (2012). Dyadic attributes relevant in the context of innovation studies include social roles, interactions, or flows of information between actors (Spielman et al. 2009a).

This methodology has been used by Isaac et al. (2007) to examine the properties of farmer knowledge transfer in an agroforestry system in Ghana. Other similar studies, particularly those seeking to investigate interdependencies between social actors and natural resources quantitatively, have been carried out in the recent past (Janssen et al. 2006; Bodin and Tengö 2012). Another tool mentioned in the literature is cognitive mapping, which has been applied in studies assessing the use of explicit knowledge, particularly in natural resource management and local knowledge systems (Isaac et al. 2009).

In terms of ISFM transfer within AKIS, there has been some concern that resource-poor farmers, especially in SSA, are greatly disadvantaged regarding information and knowledge access on soil fertility interventions (Bationo et al. 2004). Socio-economic factors, such as low literacy levels, have played a definitive role in curtailing information flow in AKIS rendering a broad section of smallholder farmers information-poor (Opara 2008; Sanginga and Woomer 2009).

Likewise, a politico-institutional element is attributed to the prevalence of agricultural information scarcity (Omosa 1998; Hazell and Wood 2008). This situation has been grossly amplified by exposure to international competition and market forces (Garforth et al. 2003; Hazell and Wood 2008). Younger, resource-endowed and educated city dwellers are more likely to use information communication technology (ICT)-based media to gain knowledge on innovations (Garforth et al. 2003; Sein and Furuholt 2012). The “digital divide” refers to the disparity in access to ICTs between poor, rural and wealthy, urban populations or northern (Europe, North America) and southern (Africa, South East Asia) countries. It has been a significant contributor to the widening of the knowledge gap between resource-poor and resource-endowed farmers (Garforth et al. 2003; Adolwa et al. 2012;).

Table 1 Evolution of theoretical perspectives on agricultural innovation (adapted from Pascucci and De-Magistris 2011; Klerkx et al. 2012)

Time period	System	Characteristics
From 1960s	Diffusion of Innovations/Transfer of Technology	• Dissemination of technology through pipeline • Single discipline driven • Focus on increased production and technology packages • Main driver is research • Institutions are external to the adoption process • Scientists are the main innovators • Farmers are either adopters or laggards • Technology adoption is the ultimate goal
From 1970s - 1980s	Farming Systems Research	• Use of surveys to capture farmers' constraints • Multi-disciplinary • Efficiency gains (input-output) • Modified packages in line with farmer constraints • Farmers' constraints and needs are main drivers • Integration of the agro-ecological and farm-economic context • Scientists and extensionists are the main innovators • Farmers are sources of information • Farming system fit is the ultimate goal
From 1990s	Agricultural Knowledge and Information Systems	• Participatory research • Interdisciplinary • Farm-based livelihoods • Joint production of technologies and sharing of knowledge • Driven by farmer demand • Science and technology develop and are embedded within social, political, economic and agro-ecological context • Farmers, scientists, and extensionists are main innovators • Farmers are also experimenters • Goal is to co-evolve technologies to fit livelihood systems better
From 2000s	Agricultural Innovation Systems (AIS) and Agricultural Knowledge and Innovation Systems	• Innovation through multi-actor processes and partnerships • Trans-disciplinary, holistic systems perspectives • Emergence of value chains and institutional change • Shared learning, change, and networking • Driven by responsiveness to changing contexts • Science and technology develop and are embedded within the social, political, economic, and agro-ecological context • Innovators entail multiple actors • Farmers are partners, innovators or entrepreneurs and exert demands • Capacity to innovate, learn and change is the goal

1.4 System innovations: From awareness to impacts

Farmer decision making leading to the adoption of soil fertility innovations is a complex process influenced by various socio-economic and biophysical factors in a given contextual setting (Tiwari et al. 2008). There is a broad literature from a multitude of studies on the aspect of agricultural innovation adoption, in general, and system innovations, in particular. In some quarters, adoption is recognized as a step-wise process that begins with the awareness of an innovation before proceeding to the actual adoption (Dimara and Skuras 2003; Kabunga et al. 2012; Lambrecht et al. 2014). Modeling the awareness step of adoption is imperative. Especially in cases where a large section of the target population is unaware of the innovation due to its complexity as in organic agriculture (Dimara and Skuras 2003), or due to civil strife or conflicts that mitigate research and development initiatives such as mineral fertilizer application in eastern DR Congo (Lambrecht et al. 2014).

A sizeable body of literature exists on household and farm-level constraints to system innovation adoption. Non-farm income from non-agricultural sources has been shown to foster the adoption of ISFM and other system innovations (Marenya and Barrett 2007; Tiwari et al. 2008; Odendo et al. 2009). Labor, whether hired or family labor, is shown to positively influence the adoption of system innovations such as integrated pest management (Dorfman 1996) and the SRI innovation (Noltze et al. 2012). Resource endowment has been widely demonstrated to be key to the uptake of system innovations whose different components might be costly for a smallholder farmer to implement. For instance, land-owning farmers are likely to invest in system innovations e.g. improved soil conservation technology (Tiwari et al. 2008) or CA (Arslan et al. 2014). Wollni et al. (2010) reported that farmers with secure tenure to their land are likely to adopt CA. However, Knowler and Bradshaw (2007) argue in their review of CA and other similar innovations that the overall effect of farm size is inconclusive. Institutional factors have been reported to be drivers of system innovation adoption as they increase farmer access to credit and production or marketing information through linkages with farmer associations (Tiwari et al. 2008; Noltze et al. 2012). Participation in markets has also been shown to spur the adoption of system innovations such as CA (Wollni et al. 2010). However, Noltze et al. (2012) suggested that access to markets was not important for low external-input innovations such as SRI. The aspect of farm level trade-offs within the framework of system innovation adoption has been addressed in far fewer studies. Corbeels et al. (2014) applied simulation models to show trade-offs between crop residue for mulch use and fodder. Jaleta et al. (2013) similarly analyzed crop residue use in a mixed crop-livestock system where higher ownership of livestock was observed to decrease the adoption of CA practices. All of these studies underline socioeconomic indicators as well as supporting institutional structures influencing adoption decisions by farmers.

Several studies have controlled for plot-related variables such as plot size, slope, and altitude in models to estimate adoption of soil fertility technologies (Tiwari et al. 2008; Kassie et al. 2013). Some studies have also assessed the role of soil quality on the adoption of soil fertility innovations. In general, soil quality variables were found to be important determinants of adoption. While Wollni et al. (2010) reported increased adoption of soil conservation practices in areas with low soil quality; findings in a study by Arslan et al. (2014) on CA adoption in Zambia were mixed. Noltze et al. (2012) observed an increase in SRI adoption in plots with loamy soils and of low salinity.

The effects of system innovations on crop yields and household and farm income are reported for cross-sectional data (Noltze et al. 2013) as well as panel data (Arslan et al. 2014). Impacts have also been assessed by simulation models (Corbeels et al. 2014; Pannell et al. 2014). There is a consensus from these studies that system innovations confer positive effects on yield and household income but this depends on the prevailing circumstances under which a farmer operates. A study in western Kenya that used on-farm experimental data with four ISFM treatments in a randomized complete block design is one of the very few ISFM impact studies (Odendo et al. 2007). Here, ISFM options were reported to be economically viable. Similar results were reported for West Africa (Gnahoua et al. 2016) and southern Africa (Nezomba et al. 2015).

In methodologically assessing adoption of system innovations, probit and logit models have been used in studies where the dependent or response variable was dichotomous (or binary) in nature (D'Emden et al. 2006; Amudavi et al. 2009; Mugwe et al. 2009; Odendo et al. 2009; Adolwa et al. 2012). According to Allison (1999), they are the standard methods of analysis for binary dependent variables. The trivariate probit model has been utilized in estimating the potential impact of information acquisition on system innovation adoption (Genius et al. 2006). Other studies have used a double-hurdle approach to model sequential decision making by farmers (Langyintuo and Mungoma 2008; Noltze et al. 2012; Arslan et al. 2013). Several studies assessing the adoption of package technologies entailing interrelated components have utilized models such as the multinomial probit model (Dorfman 1996), the multivariate probit model (Teklewold et al. 2013a), and the multivariate Bayesian model (Aldana et al. 2011). Sequential adoption of package technologies has been estimated using ordered probit models (Wollni et al. 2010). Attempts have also been made to understand the adoption of system innovations as a dynamic process transcending the field, farm, and regional scale. In one study by Corbeels et al. (2014), for instance, a case was made for understanding determinants of CA adoption and its impacts. Accordingly separate simulation models were applied at the field scale (DSSAT modeling platform) and the farm and village scale (Olympe model, Crop-Livestock Interaction at Farm-scale (CLIF) model), and regional/institutional level (Qualitative expert-based Assessment Tool of CA adoption in Africa (QAToCA) tool). Endogenous switching regression frameworks, propensity score matching and regression techniques have been applied in assessing effects of these innovations (Bolwig et al. 2009; Teklewold et al. 2013b). These methods account for the heterogeneous impacts of technologies thus better measure their causal effects.

1.5 Scales of analysis

The framework used for the entire study to comprehensively assess the adoption of ISFM is shown in Figure 4. The analysis was done at the field, farm and regional scales using different analytical approaches some of which cut across scales. At the field scale, the main idea was to assess how technical indicators influence farmer decision making. This necessitated collecting soil data from a random sample of farmers' fields at the two study sites. This data together with other plot level variables were subsequently included in an ordinal regression model to estimate plot-level effects on adoption.

At the farm scale, data from survey questionnaires was utilized to analyze farm level economic activities (including prices of inputs and outputs, labor costs) and crop yields, allowing assessment of the effects of ISFM on farm productivity and income. Socio-demographic factors such as off-farm income and occupation, age, and household size were among the variables included in the regression model to estimate adoption at this level. Resource allocation was another important factor examined at this level. Oftentimes, resource-endowed households have more purchase options and assets thus are likely to allocate fertilizer and organic inputs across all or most of their plots (Vanlauwe et al. 2015). Household-level variables and farm-level indices such as total livestock units (TLU) were used to assess the link between the propensity for resource allocation and adoption.

The regional scale analysis encompassed an examination of the role of social or informal networks and formal networks in creating awareness of ISFM knowledge. The role of enabling institutions, which foster market and credit access, was tackled at this level using a regression model. Information flows within the AKIS were assessed using social networking tools. This framework thus enabled an examination of ISFM awareness, uptake and impacts at different interacting scales with the aid of both qualitative and quantitative data.

1.6 Research gaps

The low absorption of ISFM and other system innovations in African farming systems is widely discussed in the literature (Odendo et al. 2007; Bationo et al. 2011; Vanlauwe et al. 2014b). Although some attention has been given to addressing this problem, several knowledge gaps concerning ISFM adoption remain. Firstly, there are very few documented studies associated with AKIS in eastern and western Africa, particularly about their strengths and weakness in creating dissemination or uptake pathways for agricultural innovations such as ISFM. More emphasis has been placed on the impact of social networks on adoption, but this has mainly been restricted to single technologies (Conley and Udry 2001; Bandiera and Rasul 2006; Matuschke and Qaim 2009; Kabunga et al. 2012; Maertens and Barrett 2013; Lambrecht et al. 2014). Secondly, there is growing consensus that system innovation adoption is not merely a binary process but tends to be partial and incremental or stepwise (Arslan et al. 2014; Pannell et al. 2014). Nevertheless, there exists a gap on the stepwise, cumulative adoption of ISFM adoption as previous studies have only estimated a binomial process. Thirdly, previous studies have not adequately explained the influence of different soil quality dimensions on the adoption of soil fertility innovations, mainly due to an over-reliance on farmer-reported categories. Many of these studies use farmer-reported or soil classification categories as a measure of soil quality rather than the actual soil quality indicators, the only exception being a study by Noltze et al. (2012). In the case of ISFM, it may be necessary to use more detailed soil data for better capture of the different dimensions of soil quality that may influence the nuanced adoption of ISFM. Fourthly, there are hardly any studies that have assessed micro-level effects of ISFM controlling for the heterogeneity of farming households, farming systems, and agro-ecological conditions.

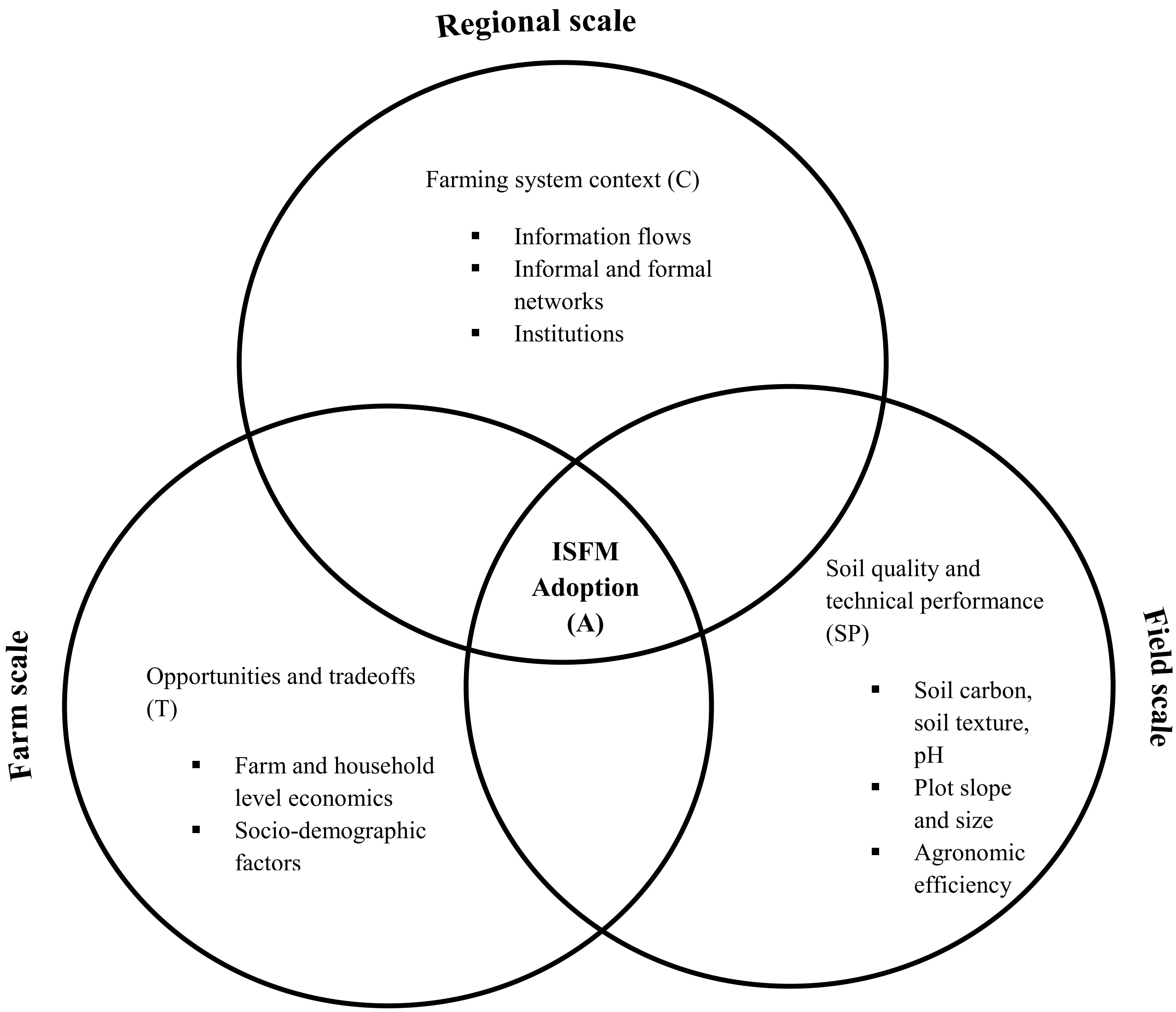

Figure 4 Conceptual framework showing the determinants of ISFM adoption at three scales. Adoption= Performance + Tradeoffs + Context + $(SP \times T \times C)_{interactions}$ (adapted from Corbeels et al. 2014).

1.7 Research questions and objectives

The key questions addressed in this study, which was carried out in Tamale, Ghana, and Kakamega, Kenya were:

- Are current agricultural knowledge and innovation systems in East (Kenya) and West (Ghana) Africa effective in communicating and disseminating ISFM?

- Does soil quality influence ISFM uptake by farmers? Which specific socioeconomic and politico-institutional factors drive ISFM uptake?
  - Are obstacles to effective adoption of ISFM different across East (Kenya) and West Africa (Ghana)?
- How does ISFM adoption impact maize yield and total household income?

To tackle these questions the objectives of the study were:

1. To assess the efficacy of agricultural knowledge and innovation systems in East (Kenya) and West (Ghana) Africa in the communication and dissemination of ISFM (Chapter 2);
2. To investigate how specifically soil quality, and more broadly socio-economic status and institutional factors, influence farmer adoption of ISFM (Chapter 3);
3. To assess the impact ISFM on maize yield and total household income of smallholder farming households (Chapter 4).

References

Adolwa, I.S., Okoth, P.F., Mulwa, R.M., Esilaba, A.O., Mairura, F.S., and Nambiro, E. 2012. Analysis of communication and dissemination channels influencing the adoption of Integrated Soil Fertility Management in western Kenya. *The Journal of Agricultural Education and Extension* 18(1): 71–86.

Aldana, U., Foltz, J.D., Barham, B.L., and Useche, P. 2011. Sequential adoption of package technologies: The dynamics of stacked trait corn adoption. *American Journal of Agricultural Economics* 93(1): 130–143.

Allison, P.D. 1999. Comparing logit and probit coefficients across groups. *Sociological Methods and Research* 28(2): 186–208.

Amudavi, D.M., Zeyaur, R.K., Wanyama, J.M., Midega, C.A.O., Pittchar, J., Hassanali, A., and Pickett, J.A. 2009. Evaluation of farmers' field days as a dissemination tool for push-pull technology in western Kenya. *Crop Protection* 28(3): 225–235.

Andersson, J.A., and D'Souza, S. 2014. From adoption claims to understanding farmers and contexts: A literature review of conservation agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment* 187: 116–132.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., and Cattaneo, A. 2014. Adoption and intensity of adoption of conservation farming practices in Zambia. *Agriculture, Ecosystems and Environment* 187: 72–86.

Bandiera, O., and Imran, R. 2006. Social networks and technology adoption in northern Mozambique. *The Economic Journal* 116(514): 869–902.

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E., Thiombiano, L., and Waswa, B. 2012. Knowing the African soils to improve fertilizer recommendations. In *Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT)*, ed. Kihara, J., Fatondji, D., Jones, J.W., Hoogenboom, G., Tabo, R., and Bationo, A. 19–42. Dordrecht, Netherlands: Springer.

Bationo, A., and Waswa, B.S. 2011. New challenges and opportunities for integrated soil fertility management in Africa. In *Innovations as Key to the Green Revolution in Africa*, ed. Bationo, A., Waswa, B., Okeyo, J.M., Maina, F., and Kihara, J. 3–17. Dordrecht, Netherlands: Springer.

Bationo, A., Kimetu, J., Ikerra, S., Kimani, S., Mugendi, D., Odendo, M., Silver, M., Swift, M.J., and Sanginga, N. 2004. The African network for soil biology and fertility: New challenges and opportunities. In *Managing nutrient cycles to sustain Soil fertility in Sub-Saharan Africa*, ed. Bationo, A. 1–23. Nairobi, Kenya: Academy Science Publishers (ASP).

Bodin, Ö., and Tengö, M. 2012. Disentangling intangible social–ecological systems. *Global Environmental Change* 2(2): 430–439.

Bolwig, S., Gibbon, P., and Jones, S. 2009. The economics of smallholder organic contract farming in tropical Africa. *World Development* 37: 1094–1104.

Chagomoka, T., Unger, S., Drescher, A., Glaser, R., Marschner, B., and Schlesinger, J. 2016. Food coping strategies in northern Ghana. A socio-spatial analysis along the urban–rural continuum. *Agriculture and Food Security* 5(1): 265-280.

Conley, T., and Udry, C. 2001. Social learning through networks: The adoption of new agricultural technologies in Ghana. *Agricultural and Applied Economics Association* 83(3): 668–673.

Corbeels, M., de Graaff, J., Ndah, T.H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H.D., and Adolwa, I.S. 2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems and Environment* 187: 155–170.

D'Emden, F.H., Llewellyn, R.S., and Burton, M.P. 2006. Adoption of conservation tillage in Australian cropping regions: An application of duration analysis. *Technological Forecasting and Social Change* 73(6): 630–647.

Dimara, E., and Skuras, D. 2003. Adoption of agricultural innovations as a two-stage partial observability process. *Agricultural Economics* 28(3): 187–196.

Dorfman, J.H. 1996. Modeling multiple adoption decisions in a joint framework. *American Journal of Agricultural Economics* 78(3): 547–557.

FAO. 2015. FAO statistical pocketbook: World food and agriculture. http://www.fao.org/3/a-i4691e.pdf. Accessed 16 June 2016.

FAO. 2014. Food and nutrition in numbers: 2014. http://www.fao.org/3/a-i4175e.pdf. Accessed 30 September 2015.

FAOSTAT. 2015. Food and Agriculture Organization of the United Nations Statistics Division. http://faostat3.fao.org/download/Q/QC/E. Accessed 05 September 2016.

Garforth, C., Khatiwada, Y., and Campbell, D. 2003. Communication research to support knowledge interventions in agricultural development: Case studies from Eritrea and Uganda. Paper presented at the Development Studies Association Conference, Glasgow, UK. 10-12 September 2003.

Genius, M., Pantzios, C.J., and Tzouvelekas, V. 2006. Information acquisition and adoption of organic farming practices. *Journal of Agricultural and Resource Economics* 31(1): 93–113.

Gnahoua, J.-B.G., Ettien, D.J.B., N'zué, B., Ebah, C., Koné, B., de Neve, S., and Boeckx, P. 2016. Intensification pathway for improvement of smallholder cassava production systems in southern Côte D'Ivoire. *Experimental Agriculture* 52(1): 1–15.

Hazell, P., and Wood, S. 2008. Drivers of change in global agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1491): 495–515.

Hulsebosch, J. 2001. The use of RAAKS for strengthening community-based organisations in Mali. *Development in Practice* 11(5): 622–632.

Isaac, M.E., Dawoe, E., and Sieciechowicz, K. 2009. Assessing local knowledge use in agroforestry management with cognitive maps. *Environmental Management* 43(6): 1321–1329.

Isaac, M.E., Erickson, B.H., Quashie-Sam, S.J., and Timmer, V.R. 2007. Transfer of knowledge on agroforestry management practices: The structure of farmer advice networks. *Ecology and Society* 12(2): 32-43.

Jaleta, M., Kassie, M., and Shiferaw. B. 2013. Tradeoffs in crop residue utilization in mixed crop–livestock systems and implications for conservation agriculture. *Agricultural Systems* 121: 96–105.

Janssen, M.A., Bodin, Ö., Anderies, J.M., Elmqvist, T., Ernstson, H., McAllister, R.R.J., Olsson, P., and Ryan, P. 2006. Toward a network perspective of the study of resilience in social-ecological systems. *Ecology and Society* 11(1): 15-34.

Kabunga, N.S., Dubois, T., and Qaim. M. 2012. Heterogeneous information exposure and technology adoption: The case of tissue culture bananas in Kenya. *Agricultural Economics* 43(5): 473–486.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., and Mekuria, M. 2013. Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change* 80(3): 525–540.

Kessler, C.A., van Duivenbooden, N., Nsabimana, F., and van Beek, C.L. 2016. Bringing ISFM to scale through an integrated farm planning approach: A case study from Burundi. *Nutrient Cycling in Agroecosystems* 105(3): 249–261.

Klerkx, L., van Mierlo, B., and Leeuwis, C. 2012. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In *Farming systems research into the 21st century: The new dynamic*, ed. Darnhofer, I., Gibbon, D., and Dedieu, B. 457–483. Dordrecht, Netherlands: Springer.

Knowler, D., and Bradshaw, B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy* 32(1): 25–48.

Kolawole, O.D. 2013. Soils, science and the politics of knowledge: How African smallholder farmers are framed and situated in the global debates on integrated soil fertility management. *Land Use Policy* 30(1): 470–484.

Lambrecht, I., Vanlauwe, B., Merckx, R., and Maertens, M. 2014. Understanding the process of agricultural technology adoption: Mineral fertilizer in eastern DR Congo. *World Development* 59: 132–146. .

Langyintuo, A.S., and Mungoma, C. 2008. The effect of household wealth on the adoption of improved maize varieties in Zambia. *Food Policy* 33(6): 550–559.

Maertens, A., and Barrett, C.B. 2013. Measuring social networks' effects on agricultural technology adoption. *American Journal of Agricultural Economics* 95(2): 353–359.

Marenya, P.P., and Barrett, C.B. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy* 32(4): 515–536.

Matuschke, I., and Qaim, M. 2009. The impact of social networks on hybrid seed adoption in India. *Agricultural Economics* 40(5): 493–505.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merckx, R., Chianu, J., and Vanlauwe, B. 2009. Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. *Experimental Agriculture* 45(01): 61-75.

Munyua, H., and Stilwell, C. 2010. A mixed qualitative-quantitative-participatory methodology: A study of the agricultural knowledge and information system (AKIS) of small-scale farmers in Kirinyaga District, Kenya. *Library Management* 31(1/2): 5–18.

Nezomba, H., Mtambanengwe, F., Chikowo, R., and Mapfumo, P. 2015. Sequencing integrated soil fertility management options for sustainable crop intensification by different categories of smallholder farmers in Zimbabwe. *Experimental Agriculture* 51: 17–41.

Noltze, M., Schwarze, S., and Qaim, M. 2013. Impacts of natural resource management technologies on agricultural yield and household income: The system of rice intensification in Timor Leste. *Ecological Economics* 85: 59–68.

Noltze, M., Schwarze, S., and Qaim, M. 2012. Understanding the adoption of system technologies in smallholder agriculture: The system of rice intensification (SRI) in Timor Leste. *Agricultural Systems* 108: 64–73.

Odendo, M., Obare, G., and Salasya, B. 2009. Factors responsible for differences in uptake of integrated soil fertility management practices amongst smallholders in western Kenya. *African Journal of Agricultural Research* 4(11): 1303–1311.

Odendo, M., Ojiem, J., Bationo, A., and Mudeheri, M. 2007. On-farm evaluation and scaling-up of soil fertility management technologies in western Kenya. *Nutrient Cycling in Agroecosystems* 76(2-3): 369–381.

Opara, U.N. 2008. Agricultural information sources used by farmers in Imo State, Nigeria. *Information Development* 24(4): 289–295.

Omosa, E. 1998. The use and application of various communication channels at local and international levels. In: Women in agriculture and modern communication technology. Proceedings of a workshop on women in agriculture and modern communication technology Tune Landboskole, Denmark. 30 March-3 April 1998.

Pannell, D.J., Llewellyn, R.S., and Corbeels, M. 2014. The farm-level economics of conservation agriculture for resource-poor farmers. *Agriculture, Ecosystems and Environment* 187: 52–64.

Pascucci, S., and De-Magistris, T. 2011. The effects of changing regional Agricultural Knowledge and Innovation System on Italian farmers' strategies. *Agricultural Systems* 104(9): 746–754.

Probst, L., Adoukonou, A., Amankwah, A., Diarra, A., Vogl, C.R., and Hauser, M. 2012. Understanding change at farm level to facilitate innovation towards sustainable plant protection: A case study at cabbage production sites in urban West Africa. *International Journal of Agricultural Sustainability* 10(1): 40–60.

Rees, D., Momanyi, M., Wekundah, J., Ndungu, F., Odondi, J., Oyure, A.O., Andima, D., Kamau, M., Ndubi, J., Musembi, F., Mwaura, L., and Joldersma, R. 2000. Agricultural knowledge and information systems in Kenya – implications for technology dissemination and development. Agricultural Research and Extension Network. Network Paper No. 107.

Sanginga, N., and Woomer, P.L. 2009. *Integrated soil fertility management in Africa: Principles, practices and developmental process.* Nairobi: TSBF-CIAT.

Sein, M.K., and Furuholt, B. 2012. Intermediaries: Bridges across the digital divide. *Information Technology for Development* 18(4): 332–344.

Spielman, D.J., Ekboir, J., and Davis, K. 2009a. The art and science of innovation systems inquiry: Applications to Sub-Saharan African agriculture. *Technology in Society* 31(4): 399–405.

Spielman, D.J., Ekboir, J., and Davis, K. 2009b. Developing the art and science of innovation systems enquiry: Alternative tools and methods, and applications to sub-Saharan African agriculture. In *Innovation Africa: Enriching farmers' livelihoods*, ed. Sanginga, P.C., Waters-Bayer, A., Kaaria, S., Njuki, J., and Wettasinha, C. 72–83. London, UK: Earthscan.

Teklewold, H., Kassie, M., and Shiferaw, B. 2013a. Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics* 64(3): 597–623.

Teklewold, H., Kassie, M., Shiferaw, B., and Köhlin, G. 2013b. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics* 93: 85–93.

Tittonell, P., Misiko, M., and Ekise, I. 2008. Talking soil science with farmers. *Leisa-Leusden* 24(2): 15–17.

Tiwari, K.R., Sitaula, B.K., Nyborg, I.L.P., and Paudel, G.S. 2008. Determinants of farmers' adoption of improved soil conservation technology in a middle mountain watershed of Central Nepal. *Environmental Management* 42(2): 210–222.

van Mierlo, B., Janssen, A., Leenstra, F., and van Weeghel, E. 2013. Encouraging system learning in two poultry subsectors. *Agricultural Systems* 115: 29–40.

Vanlauwe, B., Descheemaeker, K., Giller, K.E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., and Zingore, S. 2015. Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Soil* 1(1): 491–508.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., and van Asten, P. 2014a. Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8: 15–22.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B., and Nolte, C. 2014b. A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research* 155: 10–13.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L., and Sanginga, N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture* 39(1): 17–24.

Vanlauwe, B. 2004. Integrated soil fertility management research at TSBF: The framework, the principles, and their application. In *Managing nutrient cycles to sustain Soil fertility in Sub-Saharan Africa*, ed. Bationo, A. 25–42. Nairobi, Kenya: Academy Science Publishers (ASP).

Wollni, M., Lee, D.R., and Thies, J.E. 2010. Conservation agriculture, organic marketing, and collective action in the Honduran hillsides. *Agricultural Economics* 41(3-4): 373–384.

World Bank. 2007. *Agriculture for Development 2008.* Washington, DC: The World Bank.

2 A comparative analysis of agricultural knowledge and innovation systems in Kenya and Ghana: Sustainable agricultural intensification in the rural-urban interface

Ivan S. Adolwa[1], Stefan Schwarze[2*], Imogen Bellwood-Howard[3], Nikolaus Schareika[3] and Andreas Buerkert[1]

[1]Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics (OPATS), Steinstr. 19, Universität Kassel, D-37213 Witzenhausen, Germany;

[2]Department of Agricultural Economics and Rural Development, Georg-August-Universität Göttingen, Platz der Göttinger Sieben 5, 37073, Göttingen, Germany;

[3]Institute of Ethnology, Georg-August-Universität Göttingen, Theaterplatz 15, 37073, Göttingen, Germany

*Corresponding author: s.schwarze@agr.uni-goettingen.de

2.1 Abstract

Agriculture remains the backbone of most African economies, yet land degradation severely hampers agricultural productivity. Over the last decades, scientists and development practitioners have advocated Integrated Soil Fertility Management (ISFM) practices to improve soil fertility. However, their adoption rates are low, partly because many farmers in Sub-Saharan Africa are not fully aware of the principles of this system innovation. This has been attributed to a wide communication gap between farmers and other agricultural actors in Agricultural Knowledge and Innovation Systems (AKIS). We add to the literature by applying innovation system approaches to ISFM awareness processes. This study aims to assess if AKIS are effectively disseminating ISFM knowledge by comparing results from two sites in Kenya and Ghana, which differ in the uptake of ISFM. Social network measures and statistical methods were employed using data from key formal actors and farmers. Our results suggest that the presence of weak knowledge ties is important for the awareness of ISFM at both research sites. However, in Kenya AKIS are more effective as there is a network of knowledge ties crucial for not only dissemination but also learning of complex innovations. This is largely lacking in Ghana where integration of formal and informal agricultural knowledge systems may be enhanced by fostering the function of informal and formal innovation brokers.

Keywords: Actor ties; Agricultural Knowledge and Innovation Systems; Ego network; Integrated Soil Fertility Management

2.2 Introduction

The importance of agriculture to Africa's national economies and farmers' livelihoods has been a major driving force for efforts fostering its sustainable intensification (Vanlauwe et al. 2010; Pretty et al. 2011; Tittonell and Giller 2013). It is well known, however, that many of Africa's soils are characterized by inherent low soil fertility mainly due to a lack of volcanic or glacial rejuvenation and prolonged nutrient mining, a problem aggravated by extremely low fertilizer use (Bationo et al. 2012a). Diminishing farm sizes in many regions of Africa have resulted in continued cropping of the same parcels of land thus leading to the depletion of essential soil nutrients, land degradation and low productivity. This calls for innovative and sustainable forms of agricultural practices to raise or at least maintain and not just exploit soil productivity. Integrated Soil Fertility Management (ISFM) is one such approach and it aims to take into account the array of often site-specific biological, chemical, physical, socio-economic and political processes that determine the effectiveness of soil fertility management (Bationo et al. 2012b). However, system innovations such as ISFM, agroforestry and conservation agriculture (CA) are knowledge-intensive, complex and involve risks, which often lead to low adoption.

Low ISFM awareness is often a result of communication gaps between farmers (the primary producers and end-users of ISFM knowledge) and other agricultural stakeholders (Sanginga and Woomer 2009; Mashavave et al. 2013). Early models of innovation transfer such as the linear (pipeline) and induced innovation models, which focus on delivering technologies to the supposed users (farmers), have failed to improve agricultural productivity in Africa (Röling 2009b, 2010; Pamuk et al. 2014). Unfortunately, agricultural scientists as well as policy makers and development agents are still much in favor of these approaches despite their limitations (Röling 2009a; Friederichsen et al. 2013). The more recent innovation systems approaches are systemic in nature and emphasize mutually interactive learning between diverse actors in an agricultural system in effect providing multiple pathways for problem solving (Ortiz et al. 2008; Röling 2010; Pascucci and De-Magistris 2011; Klerkx et al. 2012). Hence they are viewed as a viable means of fostering innovation in smallholder farming systems. A critical examination of multi-actor driven innovation processes that underpin knowledge search and utilization and their interaction with farmers' social networks is hence vital in unraveling weaknesses in the sequence of system innovation awareness, learning, and uptake. Due to the complex nature of the innovation process previous research employed network perspectives to analyze linkages between informal farmer and formal actor networks (Hoang et al. 2006; Spielman et al. 2011; Asres et al. 2012; Isaac 2012; Crespo et al. 2014; Esparcia 2014; Schut et al. 2016). While these studies reveal important network processes underpinning knowledge transfer between actor networks in an innovation system such as embeddedness (Hoang et al. 2006), centrality (Spielman et al. 2011; Crespo et al. 2014; Schut et al. 2016) and ties (Spielman et al. 2011; Isaac 2012), the relationships between informal networks of smallholder farmers and overarching formal actor networks are still not clear. To close this gap, we use a mixed methodology to shed light on processes governing knowledge exchange in Agricultural Knowledge Innovation Systems (AKIS) within a developing-country context, and subsequent relation to innovation awareness. Such studies have rarely been done for Sub-Saharan Africa (SSA). Furthermore, to our knowledge, no empirical study of this nature has been done for system innovations such as ISFM.

To this end, we compare results from two sites located in Ghana and Kenya that are comparable in terms of their farming systems, but differ in information availability and adoption levels. Key questions address the extent to which existing AKIS support ISFM innovation and whether interfaces for exchange or dissemination of knowledge between formal and informal networks are effective. Currently, there is an acute need to address the fledgling agricultural innovation systems of most African countries, which have long been encumbered by weak institutions. It is imperative to assess the nature of interactions between smallholder farmers and supporting institutional actors, and how this contributes to the innovation process. The AKIS framework can help address the discrepancy between the prolific generation of agricultural knowledge on one hand, and minimal awareness and application of that knowledge by smallholder farmers, on the other. This framework is appropriate as it highlights the key actors in a given agricultural system, their roles, and interaction and how these facilitate change, learning and innovation. This study thus aims at comparatively assessing the efficacy of two AKIS in communicating and disseminating ISFM knowledge.

2.3 Integrated soil fertility management

ISFM is a soil fertility management paradigm developed to help mitigate soil fertility decline in Africa. Integrated systems of nutrient management have been advocated in SSA and elsewhere over the last two to three decades (Smaling 1993; Stoorvogel et al. 1993). Bationo et al. (2007)

argue that only the implementation of the holistic strategy of ISFM, which addresses both biophysical and socioeconomic constraints faced by farmers, can effectively break the vicious cycle of soil degradation and poverty in many parts of Africa. More recently there has been a concerted effort to use ISFM to achieve an uniquely African Green Revolution (AGR; Bellwood-Howard 2014). The Alliance for a Green Revolution in Africa (AGRA) supported by the Bill and Melinda Gates Foundation has been at the forefront of this initiative. ISFM is defined as a set of soil fertility management practices that include the use of mineral fertilizers, improved germplasm, and organic soil amendments combined with the knowledge on how to adapt these practices to local conditions in order to maximize agronomic use efficiency of the applied nutrients and enhance soil productivity (Vanlauwe et al. 2010). The practices involved are conceptually linked in a series of steps that starts with the use of mineral fertilizers and improved germplasm, followed by the second step when organic soil amendments are added and finally the third step of local technology adaptation e.g. targeted manure application, construction of terraces to prevent soil erosion and incorporation of crop residues to recycle nutrients. Central to the ISFM paradigm is that no single component of soil fertility management can on its own lead to sustainable soil fertility management (Marenya and Barrett 2007) and that it is knowledge-driven rather than being input-intensive (Tittonell et al. 2008). ISFM aims to a) replenish soil nutrient pools, b) maximize on-farm recycling of nutrients, c) reduce nutrient losses to the environment, d) improve the efficiency of external inputs, e) make use of local, traditional and scientific knowledge, and f) integrate these into technologies that enable sustainable natural resource management.

2.4 Conceptual framework

The approach used in this study is based on the AKIS[1] framework and is underpinned by the strength of weak ties (SWT) theory proposed by Granovetter (1973), which is closely related to the more recent theory of structural holes (Burt 1992). Both theories address the aspect of non-redundant ties that lead to the acquisition of new information in networks. We use the AKIS framework to illustrate the core concept to be addressed. The SWT theory allows

[1] The concepts of Agricultural Knowledge and Information Systems and Agricultural Innovation systems (AIS) have been recently merged into Agricultural Knowledge and Innovation Systems (AKIS), more so in the European Union policy and research context (Pascucci and De-Magistris 2011; Klerkx et al. 2012).

conceptualization of the underlying processes affecting the network effectiveness in promoting innovation uptake and learning.

The AKIS framework allows a systemic approach that incorporates suitable dimensions of Agricultural Innovation Systems (AIS) into agricultural knowledge and information systems. Röling (1990) defines agricultural knowledge and information systems as a set of agricultural organizations and/or persons and the links and interactions between them, engaged in the generation, transformation, transmission, storage, retrieval, integration, and utilization of knowledge and information that work synergistically to support decision making, problem solving and innovation in a given country's agricultural domain. The three functional levels or roles within AKIS comprise primary producers, intermediaries, and end-users (Wolf et al. 2001; Klerkx et al. 2012). Primary producers in this context are actors or organizations that collect data or carry out research and end-users are decision makers in agricultural entities. Intermediaries are concerned with collecting, translating and adding value to agricultural information to service decision-support needs of end-users. In a dynamic knowledge system, actors are not limited to one particular role and a farmer can thus be concurrently a primary producer and an end-user of information (Wolf et al. 2001; Pascucci and de-Magistris 2011).

Here we refer to an AKIS comprising multiple actors linked formally or informally through exchange ties of explicit or tacit knowledge. Explicit knowledge or information can be systematized, written, stored and transferred, whereas tacit knowledge is implicit, local, context-dependent, inherently intangible resulting from talents, experience and ability (Röling 1990; Wolf et al. 2001; Adolwa et al. 2012; Klerkx and Proctor 2013). The two forms of knowledge are complementary as they may transform into one another through different types of interaction or social processes (Klerkx and Proctor 2013; Schareika 2014).

Following Spielman et al. (2011) an innovation actor is defined as someone who uses or introduces innovative knowledge. Innovation actors range from public sector entities (National Agricultural Research Stations (NARS), International Agricultural Research Centers (IARC), agricultural extension, universities, and state-owned enterprises or parastatals to collective action entities such as farmer associations, Non-Governmental Organizations (NGOs), Community-Based Organizations (CBOs) and private sector actors such as marketers, traders, creditors, companies, farmers and members of farm households. Innovation actors may fall under either institutional or organizational structures. Prell et al. (2010) describe institutions as established norms, rules, and practices that guide and constrain human behavior and actions. Institutions are classified as either formal or informal, with the former relating to laws, written contracts or other codified objects and the latter referring to social networks, beliefs, conventional practice, cultures and other similar norms (Casson et al. 2010; Prell et al. 2010). A social network is defined as a pattern of advice, friendship, communication or support that exists among members of a social system (Valente 1996; Thuo et al. 2014). In literature a distinction is also made between institutions and organizations, where the latter is defined as a group of individuals with clearly defined roles and a common purpose (Prell et al. 2010). Nonetheless, formal organizations such as government and non-government agencies, farmer associations, and universities are interlinked with institutions as they often take advantage of opportunities created by the latter (Prell et al. 2010).

Individuals (in our case farmers) and organizations typically integrate into networks with other actors to optimize resource and expertise utilization since no single actor can possess all the necessary knowledge and resources (Rycroft 2007; Spielman et al. 2009). As mentioned earlier, farmers for instance, will most likely integrate with other farmers in close social networks. Similarly, formal actors would be expected to integrate among themselves following patterns of homophily i.e. their similarities with respect to behavior (Borgatti et al. 2009; Borgatti et al. 2013). Network effectiveness hinges on the capacity of the networks to facilitate knowledge exchange (Spielman et al. 2009). Thus knowledge exchange at the interfaces of two or more networks is a critical contributory factor to the enhancement of network efficacy. Klerkx and Proctor (2013) point out that actors can optimize information delivery by engaging in knowledge exchange through different institutional interfaces. It has been established that new opportunities for learning that drive the innovation process often occur at the boundaries of two or more networks through weak ties (Granovetter 2005; Crona and Bodin 2006; Matuschke and Qaim 2009; Klerkx and Proctor 2013; Thuo et al. 2014). Weak ties are linkages between actors characterized by infrequent contact, communication or interaction in terms of knowledge exchange (Granovetter 1973; Granovetter 2005). Typical for such weak ties are those between farmers and researchers, extension agents, NGOs, financial agents, and agro-dealers (Thuo et al. 2014). Conversely, strong ties are characterized by dense networks of mutually interconnected and often homophilous actors that interact frequently (Granovetter 1973; Fritsch and Kauffeld-Monz 2010). The first premise of Granovettor's theory is that information circulating in 'strong-tie' networks of closely connected actors is often redundant. The second premise is that weak ties (also referred to as bridging ties) can be a potential source of new ideas (Figure 5).

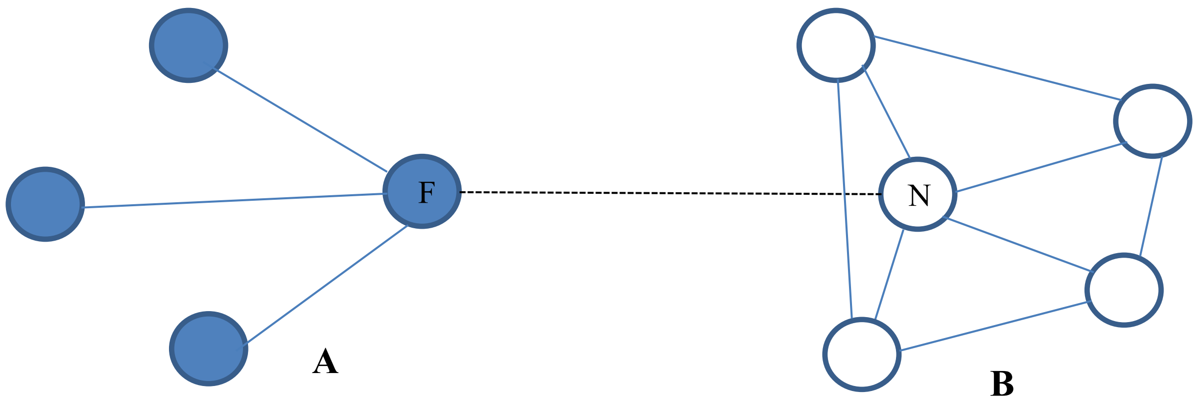

Figure 5 A pathway for innovation flow: weak 'bridging' tie from actor/node F in network A to actor/node N in network B (adapted from Borgatti and Halgin 2011).

Several studies have shown that knowledge exchange can take place at the interfaces of networks (Wolf et al. 2001; Prell et al. 2010; Klerkx and Proctor 2013). Others have demonstrated that strong ties are better suited for exchange of complex knowledge while maintaining that weak ties are suitable for the acquisition of novel, stand-alone technologies such as about fertilizer recommendations or seed varieties (Fritsch and Kauffeld-Monz 2010; Thuo et al. 2014). A well-functioning AKIS is thus characterized by network-based dissemination through both weak and strong ties as well as the embedding of actors within and outside their networks.

In this context the questions our study seeks to answer are two-fold:

1. Is there is a relationship between complete awareness of ISFM as a scientific innovation and formation of four different types of knowledge ties with AKIS actors?
2. Is there is a relationship between awareness of the different components of ISFM as a scientific innovation and formation of different types of knowledge ties with AKIS actors?

We thus want to know whether the interfaces for exchange of knowledge between formal and informal networks are effective and the extent to which the existing AKIS supports ISFM. Based on our conceptual framework we disaggregate the knowledge ties into either weak or strong, both of which may have positive implications for knowledge exchange. As mentioned earlier, weak ties are often most useful in transferring new information, whereas strong ties are relevant in internalizing newly acquired information. Moreover, weak ties become important in situations of information scarcity while strong ties foster innovation in cases where there is information abundance (Spielman et al. 2011). A further level of tie disaggregation is based on whether interaction occurs between a formal actor (e.g. a researcher) or an informal one (e.g. a neighboring smallholder farmer). To answer these questions, we need not only to know from whom the smallholders learn or who their advisors are but also the affiliations of these actors and the nature of their interactions. To complete the picture, it is important also to capture information flows among formal actors, which helps formulate possible adjustments in case of weaknesses. Therefore, there is a need for primary qualitative and quantitative data from formal and informal system actors. From the main research questions we formulate the following hypotheses for this study:

1. Those farmers with more knowledge ties to other AKIS actors have a higher propensity for complete awareness of ISFM.
2. The more ties farmers have the more components of the ISFM paradigm they are likely to be aware of.

2.5 Materials and methods

2.5.1 Description of study sites

The study was conducted in Tamale (9° 24′ N, 0° 51′ W), Ghana and Kakamega (0˚ 17' N, 34˚ 45' E), Kenya, both of which are administrative districts that contain urban and rural areas (Figure 6). Tamale Metropolis comprises a fast-growing, sprawling town of 440,000 inhabitants (Gyasi et al. 2014) and is more urbanized than Kakamega County, which has 1,661,000 inhabitants (Commission on Revenue Allocation 2013). This reflects the general trend that Ghana is more urbanized than Kenya (Mireri 2013). Both countries have a shared colonial experience and possess many similarities in the urban, cultural, political and socio-economic spheres (Otiso and Owusu 2008). Urban and peri-urban agriculture (UPA) is practiced in both cities with farmers cultivating in what are referred to as backyards and open-space confines of the city (Gyasi et al. 2014). Thus a comparative study may contribute to the understanding of the different challenges to ISFM and potential for technology adoption and up-scaling that exists at the two localities.

Tamale

Tamale lies in the Guinea-Savannah zone and receives an average annual rainfall of 1100 mm that follows a mono-modal pattern. The soils are dominated by savannah Ochrosols (derived

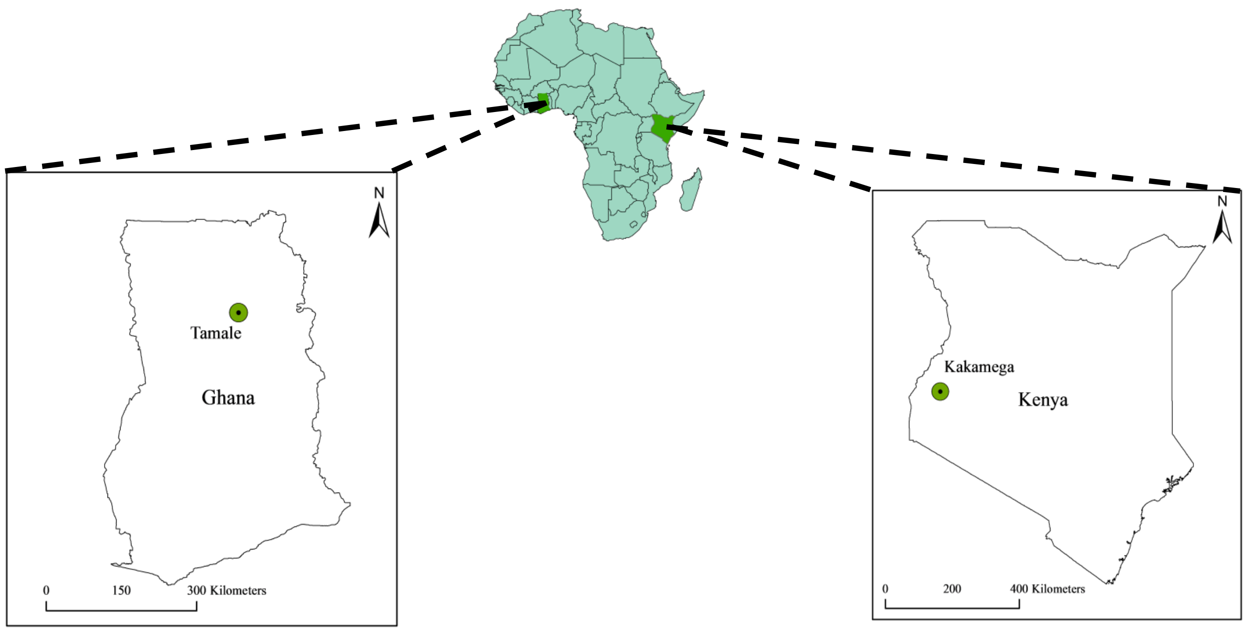

Figure 6 Map highlighting the two study regions; Tamale in Ghana and Kakamega in Kenya.

from sandstone parent material), which are generally poor in soil nutrients (Braimoh and Vlek 2006; Yiridoe et al. 2006). It has a population density of 480 persons/km^2 and is located at an average altitude of 183 m above sea level (asl) with a mostly flat terrain.

The northern region of Ghana is perceived to be the breadbasket of the country, leading in the production of cereal grains such as maize (*Zea mays L.*), rice (*Oryza sativa* or *Oryza glaberrima*), and sorghum (*Sorghum bicolor*) along with cowpea (*Vigna unguiculata*) and yam (*Dioscorea rotundata*; Yiridoe et al. 2006). Ghana's northern region has 30.3% of its population residing in urban areas while Tamale metropolis accounts for 36.5% of the total urban population (Kuusaana and Eledi 2015). Tamale metropolis comprises three sectors: the city core constitutes approximately 25 km^2 of built-up area extending up to 3 km from the central point of the city; the peri-urban area extends up to 7 km beyond boundary of the core and is about 168 km^2, and the rural area constitutes over 535 km^2 of rural outlier beyond the peri-urban boundary.

The city is highly compacted around the central business district with built-up areas occupied by civil servants and other working-class residents while it is more common to see traditional structures as one moves towards the fringes. Some of the farmers within the city core practice backyard farming for subsistence or commercial vegetable farming, whereas others farm in open spaces within the city (Gyasi et al. 2014). The peri-urban areas are used for rice, maize and vegetable production, although urban encroachment poses a substantial threat to continued farming in these areas (Gyasi et al. 2014; Kuusaana and Eledi 2015).

Kakamega

The county of Kakamega lies in the Highland Mosaic zone of the Lake Victoria basin of western Kenya. Kakamega has a bi-modally distributed annual rainfall of 1600-2000 mm whereby the first rainy season normally starts between the end of February and mid-March and lasts until July, and the second rainy season usually starts in September and lasts until December (Chitere and Mutiso 2011; Moebius-Clune et al. 2011). The average altitude of Kakamega is 1535 m asl. The inner sections of the county close to the center are considered to be in the humid upper midland agro-ecological zone whereas the outer sections are classified as humid and sub-humid lower midlands (Jaeztold et al. 2005). The center of the county receives the highest amount of rainfall and it is where Kakamega forest, the last remnant of equatorial forest in Kenya, is located. The heavily leached soils are classified as ferralo-orthic Acrisols (well drained, deep sandy clay/clay soils), ferralo-orthic/chromic Acrisols (well drained, very deep sandy clay/clay soils) and humic Acrisols (well drained, sandy clay/clay soils) with acidic humic topsoil (Jaetzold et al. 2005).

Kakamega County has a total population of 1.6 million and a population density of 544 persons/km^2, which is one of the highest population densities in Kenya (Commission on Revenue Allocation 2013). The urban population comprises 15.2% of the total county population and is spread within the towns of Kakamega (91,800), Mumias (100,000) Butere (12, 800), Lumakanda (10,6000) and Malava (4,100; Commission on Revenue Allocation 2013; Ngetich 2013).

Farming is dominated by maize that is intercropped with legumes such beans and cowpeas (Jaetzold et al. 2005). Livestock also play an essential role with cattle, sheep, and goats being commonly reared. Sugarcane (*Saccharum officinarum*) is planted as a cash crop in the humid and sub-humid midland zones, whereas tea (*Camellia sinensis*) is the main cash crop in the humid upper midland agro-ecological zones making the area under cash crops 30% of the total (Ngetich 2013). Farmers use the two rainy seasons to plant cereals, legumes, and vegetables twice except for the northern part of the county (Kabras) where farmers plant only once (Chitere and Mutiso 2015).

2.5.2 Data collection and analysis

Interviews with key informants and social network analysis methods

Key formal organizations active in urban, peri-urban and rural agriculture were identified in Tamale through a multi-stakeholder workshop facilitated by the Resources Centres for Urban Agriculture and Food Security under the Urban Food^{Plus} (UFP) project. In Kakamega, these organizations were identified with the help of key informants. A total of 25 actors representing 14 key formal organizations were interviewed in Tamale from January to March, 2014. In Kakamega, 17 actors representing 15 key formal organizations were interviewed from November 2014 to February 2015. Apart from collection of network data, in-depth interviews with these actors and a selected group of farmers were carried out to obtain further insights on the AKIS. All interviews were conducted by the first author.

In network terminology, a network is made up of actors or nodes and the relationship that links them is called a tie (Hanneman and Riddle 2005; Matuschke 2008; Spielman et al. 2011). The number of actors/nodes in a network constitutes its size. The binary measures method is used to measure ties and shows not only the existence of a relationship between actors but also its direction (Matuschke 2008). This can be illustrated as follows: if actor *j* relates to actor *k* and vice versa, then $X_{jk}=X_{kj}=1$. However, if *j* relates to *k* but the reverse is not true, then $X_{jk}=1$ and $X_{kj}=0$. Applying this logic, we followed the two-step procedure ego network analysis (Matuschke 2008) where the key actors (also referred to as "egos") were asked whom they discussed agricultural information and knowledge with to determine the size of their respective networks. Since our interest was in the information ties present in the network, we asked them whether they had received or given any information on an ISFM technology to those in their network. This approach enabled us to assess the direction of the ties. Questions were also asked on how frequently they communicated so as to elicit the strength of ties. A relative scale, described by Borgatti et al. (2013), was found suitable for rating, given the ordinal nature of the data. Thus a five-point Likert scale was applied: 5 (very frequently), 4 (somewhat frequently), 3 (moderate frequency), 2 (somewhat infrequently), and 1 (very infrequently). In previous research, the frequency of contact and in some instances also emotional intensity or closeness of a bond has been applied to measure the strength of ties (Granovetter 1973; Collins and Clark 2003; Reagans and McEvily 2003). In our case, as formal actors are for the most part homogenous, the use of frequency of contact is expected to be a reliable measure of tie strength. In the next step, actors in the respective networks of these “egos”, referred to as “alters”, were similarly asked the same set of questions to obtain a more concise picture of the overall knowledge network. Additionally, we integrated smallholder farmers into the formal actor network by using data from the farm household surveys, described in the next section. Each respondent in the survey was similarly asked whether they exchanged agricultural information with formal actors and if they had received information on any ISFM practice. Thus it was possible to determine which actors had knowledge linkages to smallholder farmers. Taking smallholders as a single node, this information was subsequently combined with the formal network data.

Some other important network measures considered include betweenness, pairs and density. Betweenness is a measure of the structural position or the embeddedness of an actor in a network to show whether that actor is in a favored position to receive or convey information (Hannemann and Riddle 2005; Isaac et al. 2007). This basically describes the extent to which a given actor falls between the paths of other actors as shown by the formula below:

$$C_B(i) = \sum_{j<k} g_{jk}(i)/g_{jk}, \quad (1)$$

where C_B denotes betweenness for node *i*; $g_{jk}(i)$ = is the number of shortest paths from *j* to *k* that pass through *i*; and g_{jk} is the number of shortest paths from *j* to *k*.

Actors with high ‘betweenness’ scores are powerful as others depend on them to access other actors. In this way, they direct information flow in the system. Density (D) refers to the nodes that are actually tied as a proportion of all possible ties in a network and is calculated using the formula of Spielman et al. (2011).

$$D = \frac{\gamma}{N(N-\gamma)/2}, \qquad (2)$$

where γ denotes the total number of ties present while N is the number of nodes in the network. Density can also be calculated by dividing the number of ties by the number of pairs (Hannemann and Riddle 2005). Pairs denote the maximum number of possible ties in each ego network. We used the networking software UCINET 6.0 to calculate these network measures (Borgatti et al. 2002). Two network diagrams for both AKIS were created with the aid of the Netdraw software package within UCINET 6.0.

Farm household survey

The analysis of informal networks as well as of the awareness and adoption of ISFM builds on a household survey among 285 stratified randomly sampled households in Tamale and 300 households in Kakamega. The survey was carried out between July and October, 2014 in Tamale and November, 2014 and February, 2015 in Kakamega. The households were stratified into participants, that is, those who had participated in previous ISFM-linked projects, and non-participants. Participants were sampled in a systematic random manner from compiled lists. In Tamale, listings of participant farmers were drawn from the AGRA ISFM project, coordinated by the Savannah Agricultural Research Institute (SARI). An additional list comprised farmers who participated in ISFM trainings carried out by the Millennium Development Authority in conjunction with SARI around the same time. Similarly, in Kakamega participant farmers were also drawn from lists of ISFM projects funded by AGRA and coordinated by the Kenya Agricultural Research and Livestock Organization (KARLO). Lists were also obtained from officials representing farmers that had been trained on ISFM by the International Centre for Tropical Agriculture (CIAT). Non-participants were selected from a randomly generated list of farmers at both sites (Agricultural Sector Development Support Programme 2014; Bellwood-Howard et al. 2015).

The face-to-face interviews conducted by the first author with the assistance of trained enumerators, were based on a structured questionnaire. Apart from network questions, it contained sections on farm characteristics, crop production and management, economic activities (including prices of inputs and outputs), marketing of agricultural products, the institutional context of agricultural production, information channels for value addition activities as well as socio-demographic characteristics of household members. The reference period for all economic activities was the last twelve months prior to the interview.

Informal networks

The ego network approach solves the boundary specification problem by allowing bounding of networks at two levels: the "ego" actor (bounding done by a random sample) and "alter" actor. In their study on social network impact on hybrid seed adoption, Matuschke and Qaim (2009) restricted their analysis to three alters by asking farmers to name a maximum of three persons they most communicated with about agricultural decisions and if they had exchanged ISFM information. Similarly in this study, farmers (ego respondents) were restricted to three actors (alters) with whom they most frequently exchanged agricultural information. In addition, they indicated the nature of relationship with alters named to elicit degree of emotional closeness, the professional affiliation or occupation as well as frequency of communication. These ties constituted the strong ties of farmers. However, Granovetter (1973) and others argue that novel information may be transmitted through weak links i.e. through interaction with actors outside tight-knit network structures. Therefore, we randomly matched the respondents with informal actors drawn from the same village and cluster (an administrative level higher than village such as ward, division or district) as well as selected formal actors as a proxy for the existence of weak ties. Three farmers each were randomly selected at the village[2] and cluster level. They were asked if they had ever exchanged agricultural information with these actors. Additionally, the respondents indicated whether they had exchanged information with formal actors; three were local administrators (chiefs, sub-chiefs, and village elders) and six were at regional or national level and included extension agents, NGO officers, researchers, government agents, marketers[3] and input dealers. It should be noted that unlike in Kakamega (exempting village elders), local administrators in Tamale are better described as informal actors as they have very little connection with overarching government structures. Thus farmers were randomly matched with a total of 15 possible actors. T-tests after cross-tabulation with the aid of the E-Net software (Borgatti 2006) and one-way analysis of variance (ANOVA) were carried out to compare farmers' knowledge ties at different awareness levels.

[2] In the urban zones, the smallest administrative unit was rather not a village but an area within a municipality.
[3]Although there are a few marketing institutions in Tamale, the marketers that farmers deal with are often independent market ladies who would be considered informal actors. Conversely, in Kakamega market actors are often formal organizations although there is still a presence of informal marketers such as market ladies or traders.

We asked the surveyed farmers whether they were aware of any of the principles outlined by Vanlauwe et al. (2010). Only those farmers who were aware of all the steps in ISFM were said to be completely ISFM-aware (Table 2). It is worth noting that indigenous traditional knowledge is embedded within the scientifically constructed ISFM paradigm. Thus some elements of ISFM are already local practice. In this paper we do not carry further analysis on adoption aspects but rather focus on disentangling the relationships between actor tie formation and awareness of the ISFM innovation.

Table 2 Awareness and adoption of different ISFM components in Tamale (Ghana) and Kakamega (Kenya).

Description	Tamale (N=282)		Kakamega (N=300)	
	Awareness (%)	Adoption (%)	Awareness (%)	Adoption (%)
Control practice-traditional varieties and/or no fertilizer	n.a	85.85	n.a	16.00
Improved germplasm + fertilizer	64.89	2.13	99.00	8.67
Improved germplasm + fertilizer + organic amendments	53.55	3.19	97.67	7.67
Improved germplasm + fertilizer + local adaptation	44.33	4.61	92.67	23.33
Improved germplasm + fertilizer + organic amendments + local adaptation (crop residues and/or ridging)	40.43	4.26	92.67	25.86
Improved germplasm + fertilizer + manure/compost + local adaptation (lime and/or terraces)[a]	n.a	n.a	41.00	18.64

[a]In the case of Kakamega, knowledge of either lime or terraces was crucial due to the constraints of acidity and erosion. n.a. - not applicable

2.6 Results and discussion

2.6.1 A descriptive overview of formal AKIS networks

The network diagrams compiled with the UCINET software are shown in Figures 7 and 8. Farmer associations, NARS, extension, agro-dealers, and NGOs are central in the Tamale network while IARC, marketers and creditors are peripheral (Figure 7). The activities of the Savannah Farmers Marketing Company, one of the few market organizations in the northern region, have been hampered by lack of funding and over-dependence on short-term projects.

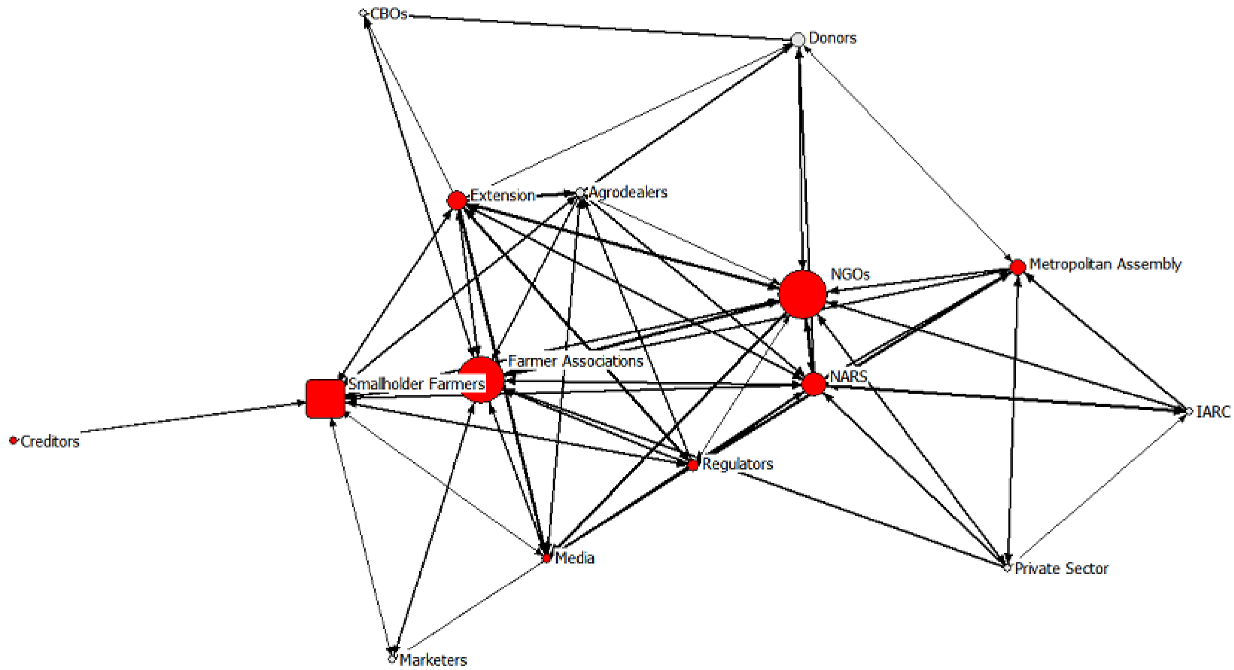

Figure 7 Graph of a directed formal AKIS network in Tamale, Ghana. Red/dark circles represent ego actors; node size is calculated based on betweenness; line thickness denotes strength of ties.

An interview session with this actor revealed that they have been unable to relay market information to farmers due to the high costs of the short message service (SMS). On the other hand, IARC, are less present as they often work through intermediaries such as NGOs. Farmer associations and NGOs are well embedded in the Tamale knowledge network and are the most important intermediaries and brokers of information as shown by the relatively high betweenness measures (Table 3).

There are several NGOs in Tamale such as the Urban Agriculture Network (URBANET) and Presbyterian Mile Seven that have played an active role in training farmers on group dynamics. The same NGOs have been used as platforms by several organizations to disseminate agricultural technologies to farmers. Their ties to different actors and their structural position in the network render them crucial intermediaries of new information in the system. Spielman et al. (2011) give a similar account of the importance of NGOs in an Ethiopian rural innovation system.

Table 3 Network measures for formal knowledge actors in Tamale, Ghana.

	Size	Ties	Pairs	Density	Betweenness
Extension	9.00	41.00	72.00	56.94	7.42
Farmer Associations	9.00	27.00	72.00	37.50	26.00
NGOs	10.00	42.00	90.00	46.67	26.70
NARS	9.00	35.00	72.00	48.61	10.62
Metropolitan Assembly	6.00	17.00	30.00	56.67	6.00
Marketers	2.00	2.00	2.00	100.00	0.00

Farmer associations and NGOs are similarly well centered in the Kakamega AKIS (Figure 8). Although actors at the other end of the value-chain like marketers still appear to be on the periphery, they have many more ties and are better integrated in the network.

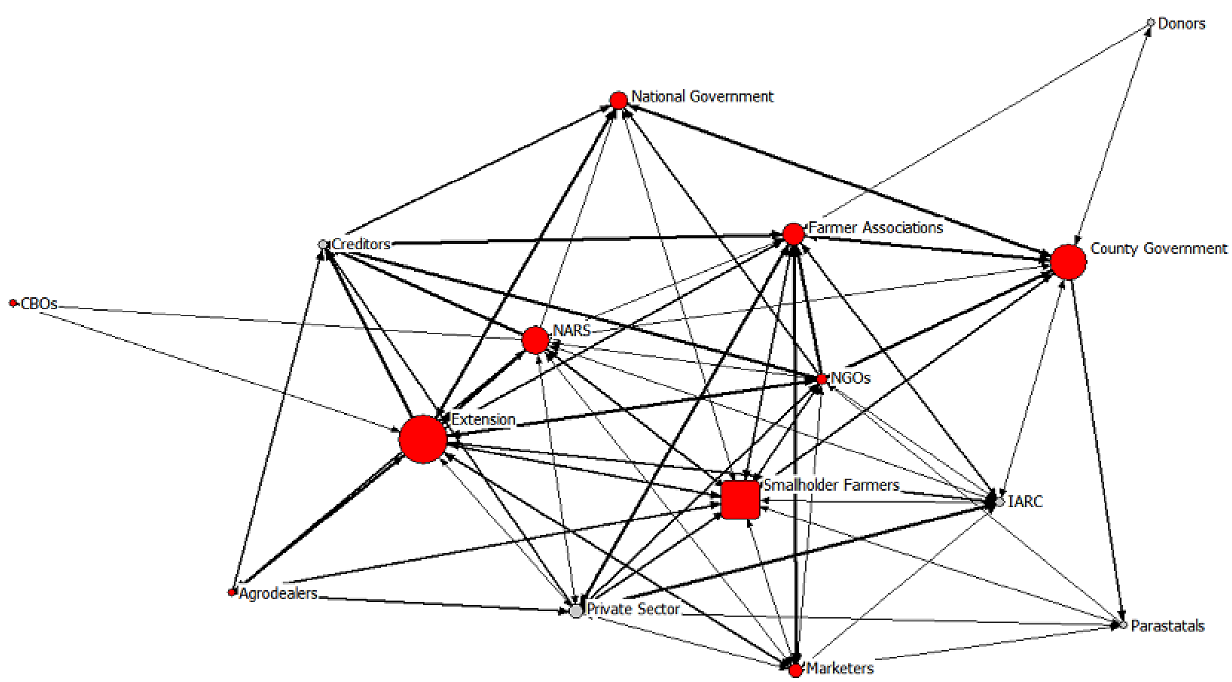

Figure 8 A directed formal AKIS network in Kakamega, Kenya. Red/dark circles represent ego actors; node size is calculated based on betweenness; line thickness denotes strength of ties.

Market organizations such as Mumias District Federation for Soybean Organization (MUDIFESO) are actively engaged not only in disseminating market information to farmers but also information on soil fertility management, good agronomic practices, and value addition. They also frequently organize farmer field days and workshops and have close links with farmers; in fact most of their officials are farmers themselves. Here extension and county government, and to a lesser extent NARS, are the most important intermediaries and brokers of agricultural knowledge as shown by their higher betweenness measures (Table 4). A reason for this may be the strong presence of these two players, particularly the extension agents, in agricultural intervention projects funded by the national/county government (e.g. the "Njaa Marufuku" Kenya programme) or international donors.

Table 4 Network measures for formal knowledge actors in Kakamega, Kenya.

	Size	Ties	Pairs	Density	Betweenness
Extension	11.00	58.00	110.00	52.73	23.22
Farmer Associations	7.00	28.00	42.00	66.67	8.50
NGOs	10.00	63.00	90.00	70.00	3.40
NARS	12.00	70.00	132.00	53.03	11.09
County Government	8.00	27.00	56.00	48.21	16.83
Marketers	8.00	44.00	56.00	78.57	3.73

Nonetheless, extension agents have been known to focus on elite farmers who are often best placed to organize themselves in functional groups, at the expense of poorer, smallholder farmers (Fujisaka 1994; Hoang et al. 2006). Whether this high interaction of extension agents with other formal actors translates to increased filtering down of information to all farmers is not clear.

Following the phenomenon of homophily, informal actors (smallholder farmers) and formal actors (researchers, extensionists, agrodealers etc) are likely to be in different networks. In this study, we have formal actors encompassed within a single network (formal AKIS) interacting or linked with the individual ego networks of smallholder farmers. These ego networks were coalesced and integrated as a single unit or node within the formal AKIS for purposes of showing this hypothetical relationship (Figures 7 and 8). It is interesting to note that smallholder farmers in the Kakamega network are more closely embedded within the formal network than their counterparts in Tamale. In order to observe the more detailed nuances of these relationships, subsequent discussion will shed light on how diverse actors interact and are mutually embedded through a combination of strong and weak ties.

2.6.2 Social networks of smallholders

In Tamale, 50% of the farmers mentioned three strong ties whereas in Kakamega their share was 73% (Table 5). Overall, the majority share of strong ties was informal (i.e. farmer-to-farmer interaction) in both Tamale and Kakamega farmer networks. This is expected as it has been widely noted that actors tend to form strong ties along homophilous lines (Borgatti and Halgin 2011).

Table 5 Strong network ties in Tamale (Ghana) and Kakamega (Kenya)

No. of mentioned ties	Strong ties (Tamale)			Strong ties (Kakamega)		
	Share of farmers mentioning ties (%)	Share of ties		Share of farmers mentioning ties (%)	Share of ties	
		Formal (%)	Informal (%)		Formal (%)	Informal (%)
0	8	n.a	n.a	11	n.a	n.a
1	17	47	53	6	10	90
2	25	24	76	10	17	83
3	50	19	81	73	9	91

With weak ties, a considerable share of farmers never exchanged information with informal actors in both AKIS, particularly at the cluster level (Figures 9 and 10). This is not surprising, since actors were selected randomly from the list of sampled farmers. At the village level in Tamale, however, more than 50% of the farmers had exchanged information with all of the three nominated actors (Figure 5). This changed with formal actors as share of farmers reporting linkages were distributed almost equally across ties. In Tamale, for example, 19% of the farmers had none, 25% one, 23% two, and 23% three weak ties to formal actors (Figure 9). The same was noted in Kakamega (Figure 6), but some farmers at both locations reported having up to five formal ties. The relatively higher interaction with formal actors is not unexpected as most weak ties tend to be associated with formalized interactions (Thuo et al. 2014).

The formal group of actors farmers most interacted with were extension agents and NGOs in Tamale, whereas in Kakamega it was chiefs followed by extension agents (Figures 11 and 12). There was no relationship between farmers' awareness of ISFM and their interaction with formal actors in Tamale but the reverse was true in the case of Kakamega. This is not surprising given the close proximity farmers have to chiefs who act as government representatives at the grassroots in Kakamega. Hoang et al. (2006) pointed out the important role of official and traditional leadership in anchoring research and development interventions. The important role of the county government in Kenya as an information broker supports this assertion (Table 3). However, the results also show that this varies with the context as chiefs and government representatives do not play this role in Ghana.

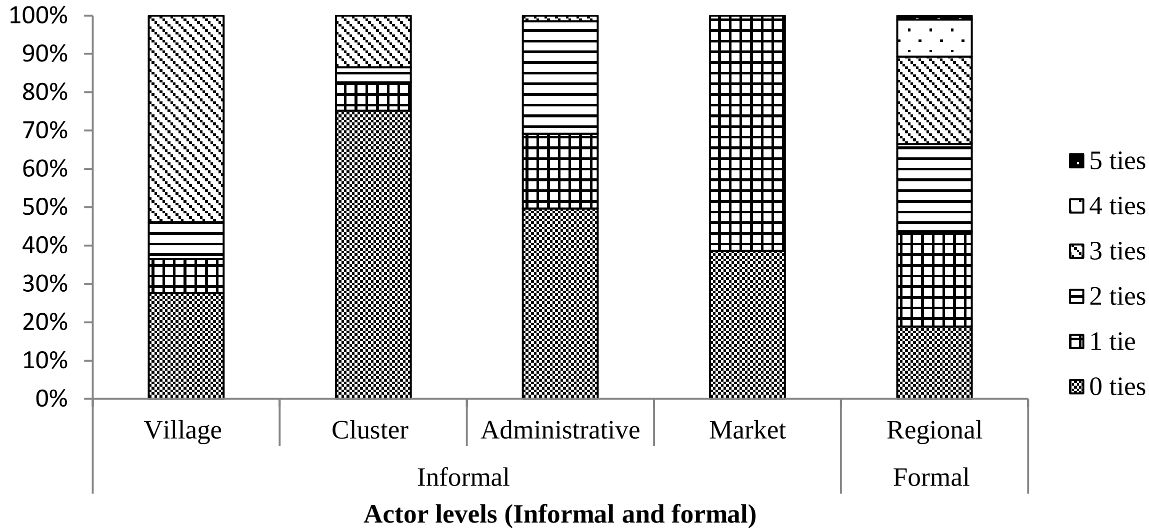

Figure 9 Share of farmers with informal and formal weak ties with actors at various levels in Tamale, Ghana.

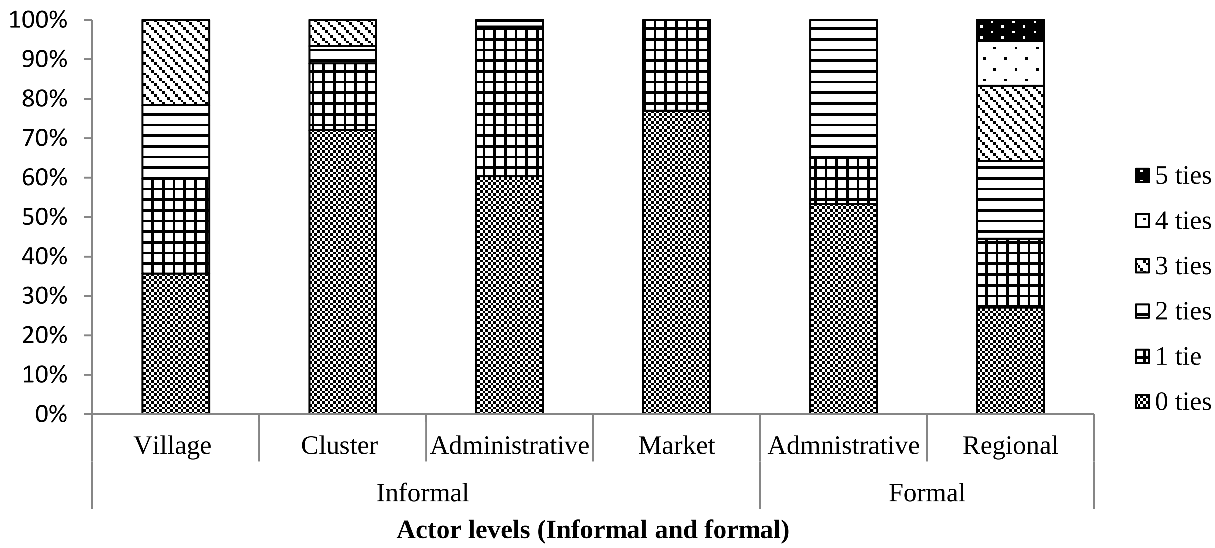

Figure 10 Share of farmers with informal and formal weak ties with actors at various levels in Kakamega, Kenya.

At Kakamega, there was a significant relationship between awareness and farmer interaction with formal actors and a higher interaction among those who were ISFM-aware with formal actors (Figure 8). The only exception was for marketers who in any case constituted a small share of formal actors in farmers' networks. Small-scale farmers are likely to benefit regarding the acquisition of new information by interacting more with formal actors such as extension agents, researchers and government officials who have been shown to be influential in directing information flow in agricultural knowledge systems (Table 3). Although the results in Figure 11 and 12 imply an active interaction between extension agents and farmers at both study locations; the former have been widely castigated for being a hindrance rather than a driving force in the dissemination of agricultural knowledge in the rural context of developing countries (Fujisaka 1994; Hoang et al. 2006).

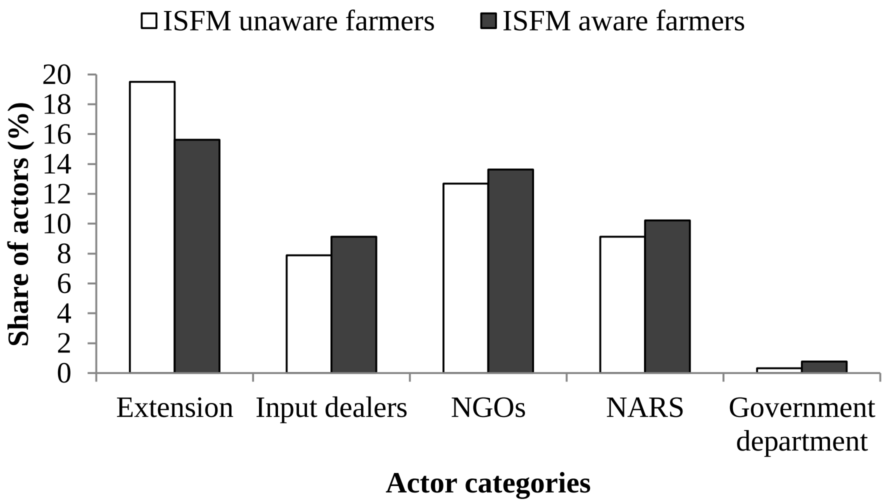

Figure 11 Occurrence of different formal actors in Tamale farmers' networks. Chi-square=10.248, df=11, *P*=0.508.

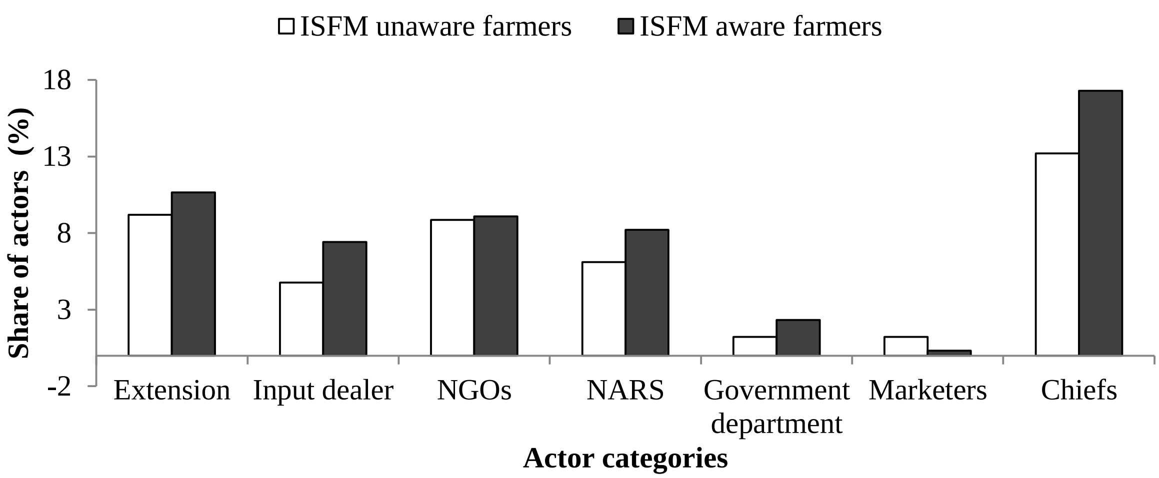

Figure 12 Occurrence of different formal actors in Kakamega farmers' networks. Chi-square=22.659, df=13, *P*=0.046.

2.6.3 Farmers' social networks and ISFM awareness

Two main null hypotheses (Ho) were tested here:

1) Incompletely aware and completely aware farmers have equal number of knowledge ties, and
2) Mean knowledge ties are equal for the different awareness levels (unaware; IG+F- aware of improved germplasm + fertilizer; IG+F+OA- aware of improved germplasm + fertilizer + organic amendments; and IG+F+OA+LA (or complete awareness)- aware of improved germplasm + fertilizer + organic amendments + local adaptation).

There were varying levels of inter-dependency between tie formations on the one hand, and complete awareness on the other. In Tamale, there was no significant difference between farmers with full knowledge on ISFM and those without regarding forming strong knowledge ties with formal actors (Table 6). However, there was a highly significant relationship between complete awareness of ISFM and weak ties to both formal and informal actors.

One-way ANOVA of strong informal ties grouped into different awareness levels showed that the groups were significantly different ($F(3, 278) = 3.961$, P=0.009))[4]. This result was somewhat surprising as there was no significant difference at 5% level between completely aware and incompletely aware farmers (Table 6).

Table 6 Tie differences between farmers with complete and incomplete ISFM awareness in Tamale, Ghana.

	Completely aware (N=114)		Incompletely aware (N=168)		
	Mean	*SD*	Mean	*SD*	
Strong formal ties	0.51	*0.90*	0.46	*0.90*	
Strong informal ties	1.86	*1.24*	1.58	*1.22*	
Weak formal ties	2.31	*1.30*	1.49	*1.23*	*
Weak informal ties	4.58	*2.43*	3.47	*2.49*	*

* mean values of number of ties significantly different at 1% level. *SD* standard deviation

Tukey post-hoc tests revealed that strong informal ties for partially aware farmers (group: IG+F+OA) were significantly less than those for unaware farmers (P=0.048) and those farmers

[4]The homogeneity of variances assumption was not violated for three ties: strong informal, weak formal and weak informal ties. The data was normally distributed for some groups according to the Shapiro-Wilk test ($p < 0.05$). For strong informal ties, all groups were distributed normally except the last group (IG+F+OR+LA). All groups for weak formal tie scores were normally distributed except for control group. Lastly, for weak informal ties groups IG+F and IG+F+M+LA were normally distributed but the other two were not. Nevertheless, one-way ANOVA is fairly robust to deviations from normality (Lix et al. 1996).

completely aware of ISFM, that is, group: IG+F+OA+LA (*P*=0.020). Thus it is reasonable to presume that grouping partially aware and unaware farmers as was done in Table 6 would in overall reduce the significance of any differences. Also, the mean values for strong informal ties for completely and incompletely aware farmers seem to be close (Table 6). Similarly, weak formal ties (F(3, 278)=11.340, *P*<0.0005)) and weak informal ties (F(3,278)=4.733, *P*=0.003) were different across groups. Tukey post-hoc tests further showed that farmers who were completely aware of ISFM (group: IG+F+OR+LA) had significantly more weak formal (*P*<0.0005) and informal ties (*P*=0.003) than those who were not ISFM aware (Table 7).

Table 7 Mean (SD) differences in number different knowledge ties at different ISFM awareness levels in Tamale, Ghana.

	Awareness			
	Unaware (N=99)	IG+F (N=32)	IG+F+OR (N=37)	IG+F+OR+LA (N=114)
Strong informal ties	1.80 (1.21)[a]	1.34 (1.23)[ab]	1.19 (1.13)[b]	1.86 (1.24)[a]
Weak formal ties	1.36 (1.21)[a]	1.62 (1.29)[a]	1.73 (1.22)[ab]	2.31 (1.30)[b]
Weak informal ties	3.41 (2.21)[a]	3.72 (2.87)[ab]	3.41 (2.87)[ab]	4.58 (2.43)[b]

IG - Improved germplasm, F - Fertilizer, OR - Organic resources, LA - Local adaptation. * Homogenous subsets (a, b) based on Tukey post-hoc test, *p* < 0.05.

In contrast, farmers in Kakamega with complete ISFM knowledge had more strong formal ties in their close networks (Table 8). Since the number of ties was limited to three, what mattered most here was not the number of ties but rather who was in the network. There were striking similarities with Tamale, however, with respect to weak ties. Farmers that were completely ISFM-aware had significantly more formal and informal weak ties than those not fully aware (Table 8).

Table 8 Tie differences between farmers with complete and incomplete ISFM awareness in Kakamega, Kenya.

	Completely aware (N=123)		Incompletely aware (N=177)		
	Mean	*SD*	Mean	*SD*	
Strong formal ties	0.37	*0.83*	0.14	*0.48*	*
Strong informal ties	2.14	*1.19*	2.28	*1.10*	
Weak formal ties	3.57	*2.00*	2.08	*2.00*	*
Weak informal ties	2.80	*2.11*	2.01	*1.98*	*

* mean values of number of ties significantly different at 1% level. *SD* standard deviation

Strong formal ties (F*(3, 183.47)=7.762, *P*=0.0001), weak formal ties (F*(3, 13.15)=20.998, *P*=0.0000), and weak informal ties (F*(3, 6.58)=4.542, *P*=0.0490) showed significant differences between groups[5] (Table 9). Post-hoc tests showed that the significant differences were mainly between partially aware (IF+F+OA) and completely aware groups. Completely aware farmers had more ties (*P*=0.0020) than partially aware (IF+F+OA) ones for strong formal ties. The same applied for weak formal ties (*P*=0.000) and weak informal ties (*P*=0.010). In most cases, those who were not aware of ISFM had zero ties to either formal or informal actors. In any case, for weak formal ties completely ISFM aware farmers had more ties (*P*=0.029).

Table 9 Mean (SD) differences in number different knowledge ties at different ISFM awareness levels in Kakamega, Kenya

	Awareness			
	Unaware (N=3)	IG+F (N=4)	IG+F+OR (N=170)	IG+F+OR+LA (N=123)
Strong formal ties	0.00	0.00	0.14 (0.49)[a]	0.36 (0.83)[b]
Weak formal ties	0.33(0.58)[a]	1.00 (2.00)[ab]	2.14 (2.00)[a]	3.57 (2.00)[b]
Weak informal ties	0.00	1.50 (3.00)[ab]	2.05 (1.96)[a]	2.80 (2.11)[b]

IG - Improved germplasm, F - Fertilizer, OR - Organic resources, LA - Local adaptation. * Homogenous subsets (a, b) based on Tukey post-hoc test, $p < 0.05$.

The significance of strong formal ties with regard to awareness points to the embeddedness of formal actors in these farmer social networks. Strong ties are crucial to internalize the complex ensemble of technologies and management practices that comprise system innovations. Thus strong formal ties have the added benefit of reinforcing already existing knowledge in addition to providing new information. Altieri (2002) suggests that strong ties between farmers and external agents are crucial for agro-ecological improvements entailing knowledge-intensive soil and crop management practices. Furthermore, Agrawal (1995) citing Chandler (1991) mentions that farmer innovation and experimentation is facilitated through the combination of existing knowledge and new information. Farmers in Kakamega have had a longer period to interact with ISFM technologies and some of the actors involved in its dissemination (Vanlauwe et al. 2004). In the case of Tamale, informal farmer and formal actor interviews revealed some gaps between what was communicated by formal actors and what farmers understood or perceived. For instance, a commercial vegetable farmer based in Gumbihini area in the city was of the view that

[5] F* (star) one way ANOVA was used as an alternative to standard one way ANOVA as distribution of data for most groups was non-normal and the variances were heterogeneous. The F* test is robust even when the assumption of homogeneity of variance is violated (Wilcox 1987).

he did not receive information on new innovations from a formal actor, yet the latter claimed to have worked closely with farmers in various agricultural projects. Interactions between farmers and formal actors were further constrained by lack of trust (emanating from farmers) and apathy on the part of the other actors, particularly the extension agents. Such perceptions are often replicated in other AKIS across Africa e.g. potato knowledge systems in Kenya, Ethiopia and Uganda (Gildemacher et al. 2009). Thus the idea that more strong ties lead to more interaction, which in turn results in higher awareness of complex knowledge among farmers is supported partly (for Kakamega) by these results, which are corroborated by previous studies of the implications of strong and weak ties (Hansen 1999). Although informal strong ties are also useful in reinforcing already acquired knowledge, this may not always be adequate when dealing with complex knowledge. In addition, farmer learning through informal village networks may not always be optimal due to acquisition of only partial information (Conley and Udry 2001).

The differentiated interaction between formal actors and smallholders in the two study areas may also be considered from a policy perspective. The agricultural sectors in Ghana and Kenya have been guided by similar agricultural policies (e.g. the structural adjustment programs) from the colonial to the present period, but there is one notable difference. The national agricultural innovation system in Kenya benefited from pioneering efforts of innovative actors, encompassing colonial-era administration and agricultural services officers and smallholder farmers, which generated institutional, organizational and policy innovations (Ochieng 2007). Some of the outcomes included land transfer to small-scale farmers, cash crop production for export by smallholders and intensified maize production (Williams 2003). This facilitated closer interconnections between the actors enabling increased awareness of technologies e.g. improved maize varieties. This contrasts with policies in Ghana, particularly in the northern region, where there has always been an adherence to mainstream agricultural policy initiatives even when they were clearly unsustainable. Nyantakyi-Frimpong and Kerr (2014) attribute the failure of numerous national and international policy initiatives in promoting agricultural intensification in part to flaws in political-economic structures and a lack of understanding of the local context. Key informant interview sessions with a key actor shed further light on the structural weakness and constraints in the maize seed sector in Ghana. Firstly, the Ghana Grains and Legumes Development Board, which is charged with the production of foundation seed, was poorly resourced. Secondly, the seed inspection division charged with the inspection and certification of seed growers was constrained in terms of labor and finances. Finally, there was a tendency of rural farmers to use recycled seeds or "saved seeds" after receiving seeds from projects. Their counterparts in the city, however, used improved maize seeds more regularly, probably due to increased proximity to input shops. This state of affairs has contributed to the lower awareness and application of ISFM principles among Tamale farmers in comparison to their counterparts in Kakamega (see Table 2).

As mentioned earlier, weak ties play a major role in the transmission of new information or knowledge. Weak ties between farmers and formal actors are often established through various research and development projects. In-depth interviews with farmers in Tamale revealed cases where AKIS actors had transferred innovative approaches on soil fertility management to farmers. In one case in Worebogu-Kukuo area, a farmer point-applied poultry manure to maximize the use of scarce organic amendments after contact with extension agents. As useful as these links are for creating awareness, as soon as the projects end farmers often revert to their prior agricultural practices (Howard et al. 2003; Nyantakyi-Frimpong and Bezner Kerr 2014). Only innovations that are low-risk, and entail low to moderate entry fees, e.g. compost or fertilizer microdosing, can be successfully adopted by rural farmers who often have to contend with site-specific biophysical and economic risks (Buerkert and Schlecht 2013; Bellwood-Howard 2014). However, in UPA systems innovation uptake may be spontaneous due, for example, to good road and market infrastructure in cities and their surroundings as well as the rather minor role played by middlemen (Buerkert and Schlecht 2013). Thus, extension systems may have a role to play in innovation awareness and uptake in the rural areas but only a minor one in UPA systems. Similarly, at Kakamega there exist numerous national and international research organizations that are loosely linked to smallholder farmers and are conduits through which they may access new information on ISFM. The Kenya Agricultural Research and Livestock Organization (KARLO), for instance, disseminated information on composting, liming and fertilizer trees, e.g. *Calliandra calothyrsus*, to farmers, mostly through channels such as farmer field days. Informal weak ties could be crucial for West African farmers who are known to use innovative techniques entailing local adaptation processes e.g. placed application of manure and crop residues (Laube et al. 2008; Buerkert and Schlecht 2013). Use of alternative organic fertilizer such as Shea butter residue (extract from the Shea tree *Vitellaria paradoxa*) mixed with litter was observed in Kumbuyili area in Tamale. Interesting convergence between the scientific and indigenous knowledge realms was also observed. A farmer in Kakpayili area reported in one in-depth interview session his own indigenous understanding of soil fertility. An increase in available nitrogen (N) at the onset of rains has been reported in several studies and is sometimes referred to as N flush (Warren et al. 1997; Ikerra et al. 1999). This farmer described a process similar to N flush as “heat from the soil which provides crops with some natural fertilizer just before the onset of heavy rains”. He observed that proper synchronization of sowing with this process of nutrient release allowed him to use much less fertilizer. He may have acquired this knowledge informally from other farmers given that this was the route he used to gain knowledge on other related innovations such as improved seed varieties and fertilizers. In the case of Kakamega, weak informal ties are crucial because of the common system of lead farmers deployed by various research and developmental organizations. Such trained farmers are likely to transfer ISFM knowledge to other farmers residing in different villages as they are often tasked by these officers to disseminate agricultural knowledge to other farmers often on a voluntary basis. Thus ISFM is not entirely an external scientific innovation as clearly farmers are using elements of it in their indigenous practice, and this is associated with their informal interaction with each other.

Apart from the information network structure and the underlying aspect of tie interactions, socio-demographic factors are bound to influence the awareness and subsequent adoption of innovations (Dutta 2009). Education is one such important factor. Innovators in Tamale differed quite significantly from non-innovators in terms of education (Table 10), with innovators having significantly more years of education than non-innovators. In the case of Kakamega, the differences between innovators and non-innovators were less pronounced, but these farmers were more educated than those in Tamale (Otiso and Owusu 2008; Table 10). The higher education levels of farmers in Kakamega relative to their counterparts in Tamale may have enhanced not only interactions with formal actors but also an understanding of the scientific format of such knowledge conveyed. Education is often a major underlying factor for the effective understanding of knowledge-intensive innovations and their consequent adoption (Marenya and Barrett 2007; Adolwa et al. 2012).

Table 10 Descriptive statistics for Tamale (Ghana) and Kakamega (Kenya).

	Tamale							Kakamega						
	All		Innovators[a]		Non-innovators[b]			All		Innovators[a]		Non-innovators[b]		
	Means	*SD*	Means	*SD*	Means	*SD*		Means	*SD*	Means	*SD*	Means	*SD*	
Farm and location characteristics														
Total land area cultivated (acres)	7.52	*9.13*	8.60	*9.94*	7.34	*9.00*		2.42	*5.56*	2.53	*5.97*	1.88	*2.62*	
Total maize area cultivated (acres)	3.66	*3.50*	4.57	*5.76*	3.50	*2.96*		1.21	*1.34*	1.25	*1.37*	0.98	*1.19*	
Tropical livestock units[c]	3.97	*7.99*	6.82	*16.12*	3.50	*5.55*		2.07	*2.02*	2.07	*1.99*	2.08	*2.21*	
HH in urban/peri-urban area (%)	33.00	*47.00*	62.00	*9.00*	28.00	*44.80*	***	20.00	*39.80*	22.00	*41.40*	8.00	*27.90*	**
Land title[d] (%)	14.00	*35.00*	32.00	*47.40*	11.00	*31.50*	***	67.00	*47.00*	65.00	*47.60*	77.00	*42.50*	
Household (HH) characteristics														
Age of HH head (years)	52.15	*13.84*	51.10	*15.53*	52.32	*13.57*		52.69	*13.14*	52.82	*13.12*	52.04	*13.37*	
Gender of HH head is male (%)	95.00	*22.50*	100.00	*00.00*	94.00	*24.20*	***	81.00	*39.00*	83.00	*38.00*	75.00	*43.80*	
HH head education level (years)	2.33	*4.95*	5.68	*6.26*	1.78	*4.48*	***	8.97	*3.93*	9.14	*3.84*	8.04	*4.31*	
HH size (no.)	12.95	*7.18*	11.22	*6.86*	13.23	*7.21*		7.23	*3.57*	7.39	*3.62*	6.38	*3.18*	*
Adult members of HH (no.)	4.46	*2.67*	4.02	*2.29*	4.53	*2.72*		4.10	*2.16*	4.19	*2.18*	3.58	*2.04*	*
HHs with off-farm occupation (%)	75.00	*54.40*	90.00	*30.40*	72.00	*57.10*	***	57.00	*49.60*	60.00	*49.00*	40.00	*49.40*	***
HH off-farm income (USD)[e]	407.79	*1092.56*	1228.95	*2353.95*	272.06	603.92	**	872.57	*1812.35*	919.94	*1868.10*	624.35	*1477.72*	

We cluster farmers into two groups: [a]those who at the very least use fertilizers and improved seeds and; [b]those who do not use any ISFM innovation.

[c] Tropical livestock units computed following Jahnke (1982) and Odendo et al. (2009)

[d] Land title defined as having a title for at least one of the plots under cultivation.

[e] 1 US Dollar = 3.99 Ghc; 1 US Dollar = 105.45 KES

*, **, ***, mean values for ISFM and Non-ISFM farmers are significantly different at 10%, 5%, and 1%, respectively

2.7 Conclusions and recommendations

Our results confirm the importance of weak ties for the awareness of ISFM at both research locations and in transmitting new information between two or more systems. To answer research question one, there was a positive relationship between complete ISFM awareness among farmers and having weak knowledge ties to both formal and informal actors. We also found that in the Kakamega AKIS there was a relationship between complete ISFM awareness among farmers and them having strong knowledge ties to formal actors. Here formal actors are much more embedded in farmers' close-knit social networks in the Kakamega AKIS, increasing farmers' access to new knowledge as well as enhancing learning. As for research question two, farmers with more weak knowledge ties were more likely to have knowledge of a higher number of ISFM components. Moreover, reaching a certain threshold of weak ties accorded the farmer complete awareness of the innovation.

Apart from strong ties being beneficial in knowledge recognition and realization (its tacit component), their usefulness becomes more apparent when combined with weak ties (Rost 2011). Thus actors in networks embedded with both weak and strong ties may formulate the most innovative solutions. What is striking in the case of the Kakamega AKIS is that the innovative farmer gains knowledge access through weak tie links to both homogeneous and heterogeneous actors, and has the additional benefit of inculcating the acquired knowledge through enhanced interaction with diverse agricultural stakeholders via strong ties. More crucially for ISFM is that strong ties between farmers and formal actors improve the capacity of the Kakamega AKIS to foster understanding of its interacting components. This seems to imply that the Kakamega AKIS communicates and disseminates ISFM knowledge more effectively than the Tamale AKIS. Hence it is not surprising that Kakamega farmers were more aware of the integrated components of ISFM than their counterparts (see Table 1). Thus from a system innovation perspective, strong formal ties are critical. While farmers' social networks are often informal, this study shows that knowledge dissemination and learning is enhanced when there are adequate interactions with formal actors.

Both sites were earmarked by AGRA for ISFM interventions because of their status as major breadbasket areas. Therefore, since 2008 ISFM has been part of the strategy among the relevant agricultural stakeholders to promote sustainable agricultural intensification in Tamale as well as

Kakamega. This study, however, underscores the need for key stakeholders (farmers, researchers and policy makers) in Tamale to re-examine the ISFM paradigm in the context of the current socio-political, economic and bio-physical environment. Bellwood-Howard (2014) argues that there is need to further streamline ISFM, where combinations applied are those that suit the resource availability context of the farmer and not the hegemonic marketization objectives of the AGR. Nevertheless, the relatively low awareness of improved seed among farmers, in particular, points to a need to address seed policy in Ghana. In the run-up to a contentious new seed law (Jehu-Appiah and Walker 2014), there is need for more research on the realities of how farmers use various types and combinations of improved, landrace, open pollinated variety, hybrid and other types of seed (Bornstein 2014).

Further integration of formal actors with farmers' local knowledge seems to be crucial for agricultural development progress in Tamale. It was noted that formal actors were focused on the initial steps of the ISFM paradigm, but were less aware of the final step, local adaptation, reflecting a limited understanding of system innovation. On the other hand, some farmers already carry out local adaptation based on their own expertise or indigenous knowledge of their environment. Therefore, a critical appraisal of the role played by powerful information mediators or brokers such as farmer associations and NGOs is necessary. A viable solution to fix poor performance of AKIS would be to shift towards multi-actor partnerships fostered by intermediaries acting as innovation brokers, whose primary purpose is to build linkages between actors and facilitate multi-actor interaction (Klerkx and Leeuwis 2009; Klerkx et al. 2012). These agents could also act as boundary spanners (Williams 2002), whose main task would be to traverse the different systems linking disparate actors in the process. This intervention is crucial given the underlying tensions such as lack of trust or feelings of superiority/inferiority, which have often curtailed knowledge transfer processes of AKIS in SSA. Lead farmers, for instance, could be suitable candidates for this purpose as they could easily act as a bridge between researchers/extension agents and other farmers. They could play a crucial role in championing new technologies among their peers. Another useful approach would be to strengthen farmer associations, which could give smallholder farmers a voice and the much-needed impetus to advocate for change. Organizations such as the One Acre Fund, which is highly active in Kakamega, have used this approach, and the results thus far are promising. Farmers here are encouraged to form small groups through which they can jointly source for credit and also make savings through a system known as ‘table banking’. These forms of farmer empowerment, though minor, are an initial step towards developing the capacity of the smallholder farmer to be a powerful player in the AKIS.

Finally, our results call for further studies in both regions that will investigate how system-wide interactions transcending the socio-political, bio-physical and economic spheres influence not only the knowledge acquisition process of knowledge-intensive innovations, but also their adoption.

Acknowledgements

This study was partly funded within Urban Food^{plus} project (FKZ: 031A242A) sponsored by the German Federal Ministry of Education and Research (BMBF) under GlobE-Research for Global Food Supply. This paper also benefited from comparative work in the rural-urban interface within FOR2432, funded by Deutsche Forschungsgemeinschaft (DFG). We are grateful for the logistical support and advice received from the University for Development Studies (UDS), the CSIR-Soil Research Institute, the Savannah Agricultural Research Institute (SARI), and the Kenya Agricultural Research and Livestock Organisation (KARLO.) We also thank the Ministry of Food and Agriculture (MoFA) officers, village elders and, last but not least, farmer and institutional actor participants in Kenya and Ghana for their cooperation. Lastly, we gratefully acknowledge the German Academic Exchange Service (DAAD) for granting a scholarship to the first author.

References

Adolwa, I.S., Okoth, P.F., Mulwa, R.M., Esilaba, A.O., Mairura, F.S., and Nambiro, E. 2012. Analysis of communication and dissemination channels influencing the adoption of Integrated Soil Fertility Management in western Kenya. *The Journal of Agricultural Education and Extension* 18(1): 71–86.

Agrawal, A. 1995. Dismantling the divide between indigenous and scientific Knowledge. *Development and Change* 26(3): 413–439.

Agricultural Sector Development Support Programme. 2014. Household baseline survey report. Kakamega County, Ministry of Agriculture, Livestock and Fisheries, Nairobi.

Altieri, M.A. 2002. Agroecology: The science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems and Environment* 93(1-3): 1–24.

Asres, A., Sölkner, J., Puskur, R., and Wurzinger, M. 2012. Livestock innovation systems and networks: Findings from smallholder dairy farmers in Ethiopia. *Livestock Research for Rural Development* 24 (9). http://www.lrrd.org/lrrd24/9/amla24164.htm. Accessed 05 August 2016.

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E., Thiombiano, L., and Waswa, B. 2012. Knowing the African soils to improve fertilizer recommendations. In *Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT)*, ed. Kihara, J., Fatondji, D., Jones, J.W., Hoogenboom, G., Tabo, R., and Bationo, A. 19–42. Dordrecht, Netherlands: Springer.

Bationo, A., Kimetu, J., Kihara, J., Traore, Z., Bagayoko, M., Bado, V., Lompo, M., Tabo, R., and Koala, S. 2012b. Cropping systems in the Sudano-Sahelian zone: Implications on soil fertility management over varied seasons. In *Lessons learned from long-term soil fertility management experiments in Africa*, ed. Bationo, A., Waswa, B., Kihara, J., Adolwa, I., Vanlauwe, B., and Saidou, K. 137–158. Dordrecht, Netherlands: Springer.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., and Kimetu, J. 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems* 94(1): 13–25.

Bellwood-Howard, I., Häring, V., Karg, H., Roessler, R., Schlesinger, J., and Shakya, M. 2015. Characteristics of urban and peri-urban agriculture in West Africa. Results of an exploratory survey conducted in Tamale (Ghana) and Ouagadougou (Burkina Faso). International Water Management Institute (IWMI) Working Paper 163. Colombo.

Bellwood-Howard, I.R.V. 2014. Smallholder perspectives on soil fertility management and markets in the African Green Revolution. *Agroecology and Sustainable Food Systems* 38(6): 660–685.

Borgatti, S.P., Everett, M.G., and Johnson, J.C. 2013. *Analyzing social networks.* London: Sage Publications.

Borgatti, S., and Halgin, D. 2011. On network theory. *Organization Science* 22: 1168–1181

Borgatti, S.P., Mehra, A., Brass, D.J., and Labianca, G. 2009. Network analysis in the social sciences. *Science* 323(5916): 892–895.

Borgatti, S.P. 2006. *E-NET software for the analysis of ego-network data.* Needham, MA: Analytic Technologies.

Borgatti, S.P., Everett, M.G., and Freeman, L.C. 2002. *Ucinet 6 for Windows. Software for social network analysis.* Harvard, MA: Analytic Technologies.

Bornstein, D. 2014. The social realities of technology transfer: Smallholder farmers' encounter with a new rice variety. *African Geographical Review* 34(1): 8–12.

Braimoh, A.K., and Vlek, P.L.G. 2006. Soil quality and other factors influencing maize yield in northern Ghana. *Soil Use and Management* 22(2): 165–171.

Buerkert, A., and Schlecht, E. 2013. Agricultural innovations in small-scale farming systems of Sudano-Sahelian West Africa: Some prerequisites for success. *Secheresse* 24: 322–329.

Burt, R.S. 1992. *Structural holes: The social structure of competition.* Cambridge, Mass.: Harvard University Press.

Casson, M.C., Marina, D.G., and Kambhampati, U.S. 2010. Formal and informal institutions and development. *World Development* 38(2): 137–141.

Chandler, P.M. 1991. The indigenous knowledge of ecological processes among peasants in the People's Republic of China. *Agriculture and Human Values* 8(1-2): 59–66.

Chitere, O.P., and Mutiso, R. (ed.). 2011. *Working with rural communities. Participatory action research in Kenya*, 2nd edn. Nairobi: University of Nairobi Press.

Collins, C.J., and Clark, K.D. 2003. Strategic human resource practices, top management team social networks, and firm performance: The role of human resource practices in creating organizational competitive advantage. *Academy of Management Journal* 46(6): 740–751.

Commission on Revenue Allocation. 2013. Kenya: County fact sheets. https://www.opendata.go.ke/Counties/County-Fact-Sheets-2nd-Ed-June-2013/qg44-68h8. Accessed 18 September 2015.

Conley, T., and Udry, C. 2001. Social learning through networks: The adoption of new agricultural technologies in Ghana. *Agricultural and Applied Economics Association* 83(3): 668–673.

Crespo, J., Réquier-Desjardins, D., and Vicente, J. 2014. Why can collective action fail in Local Agri-food Systems?: A social network analysis of cheese producers in Aculco, Mexico. *Food Policy* 46: 165–177.

Crona, B., and Bodin, Ö. 2006. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. *Ecology and Society* 11(2): 7–29.

Dutta, R. 2009. Information needs and information-seeking behavior in developing countries: A review of the research. *The International Information and Library Review* 41(1): 44–51.

Esparcia, J. 2014. Innovation and networks in rural areas. An analysis from European innovative projects. *Journal of Rural Studies* 34: 1–14.

Friederichsen, R., Minh, T.T., Neef, A., and Hoffmann, V. 2013. Adapting the innovation systems approach to agricultural development in Vietnam: Challenges to the public extension service. *Agriculture and Human Values* 30(4): 555–568.

Fritsch, M., and Kauffeld-Monz, M. 2010. The impact of network structure on knowledge transfer. An application of social network analysis in the context of regional innovation networks. *The Annals of Regional Science* 44(1): 21-38

Fujisaka, S. 1994. Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agricultural Systems* 46(4): 409–425.

Gildemacher, P., Maina, P., Nyongesa, M., Kinyae, P., Woldegiorgis, G., Lema, Y., Damene, B., Tafesse, S., Kakuhenzire, R., and Kashaija, I. 2009. Participatory analysis of the potato knowledge and information system in Ethiopia, Kenya and Uganda. In *Innovation Africa: Enriching Farmers' Livelihoods*, ed. Sanginga, P.C., Waters-Bayer, A., Kaaria, S., Njuki, J., and Wettasinha, C. 153–165. London, UK: Earthscan.

Granovetter, M. 2005. The impact of social structure on economic outcomes. *American Economic Association* 19(1): 33–50.

Granovetter, M.S. 1973. The strength of weak ties. *American Journal of Sociology* 78(6): 1360–1380.

Gyasi, E.A., Fosu, M., Kranjac-Berisavljevic, G., Mensah, A.M., Obeng, F., Yiran, G.A.B., and Fuseini, I. 2014. *Building Urban Resilience: Assessing Urban and Peri-urban Agriculture in Tamale, Ghana,* United Nations Environment Programme (UNEP), Nairobi.

Hanneman, R.A., and Riddle, M. 2005. Introduction to social network methods: University of California. http://faculty.ucr.edu/~hanneman/. Accessed 20 July 2015.

Hansen, M.T. 1999. The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly* 44(1): 82–111.

Hoang, L.A., Castella, J-C., and Novosad, P. 2006. Social networks and information access: Implications for agricultural extension in a rice farming community in northern Vietnam. *Agriculture and Human Values* 23(4): 513–527.

Howard, J., Crawford, E., Kelly, V., Demeke, M., and Jeje, J.J. 2003. Promoting high-input maize technologies in Africa: The Sasakawa-Global 2000 experience in Ethiopia and Mozambique. *Food Policy* 28(4): 335–348.

Ikerra, S.T., Maghembe, J.A., Smithson, P.C., and Buresh, R.J. 1999. Soil nitrogen dynamics and relationships with maize yields in a gliricidia–maize intercrop in Malawi. *Plant and Soil* 211(2): 155–164.

Isaac, M.E. 2012. Agricultural information exchange and organizational ties: The effect of network topology on managing agrodiversity. *Agricultural Systems* 109: 9–15.

Isaac, M.E., Erickson, B.H., Quashie-Sam, S.J., and Timmer, V.R. 2007. Transfer of knowledge on agroforestry management practices: The Structure of farmer advice networks. *Ecology and Society* 12(2): 32–54.

Jaeztold, R., Schmidt, H., Hornetz, B., and Shisanya, C. 2005. *Farm management handbook of Kenya. Natural conditions and farm management information,* 2nd edn, Vol. II. Nairobi: PHV Studios.

Jahnke, H.E. 1982. *Livestock production systems and livestock development in tropical Africa.* Kiel: Kieler Wissenschaftsverlag Vauk.

Jehu-Appiah, A-M., and Walker, C. 2014. Ghana's battle for seed sovereignty. http://newafricanmagazine.com/ghanas-battle-seed-sovereignty/. Accessed 1 August 2015.

Klerkx, L., and Proctor, A. 2013. Beyond fragmentation and disconnect: Networks for knowledge exchange in the English land management advisory system. *Land Use Policy* 30(1): 13–24.

Klerkx, L., van Mierlo, B., and Leeuwis, C. 2012. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In *Farming systems research into the 21st century: The new dynamic*, ed. Darnhofer, I., Gibbon, D., and Dedieu, B. 457–483. Dordrecht, Netherlands: Springer.

Klerkx, L., and Leeuwis, C. 2009. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technological Forecasting and Social Change* 76(6): 849–860.

Kuusaana, E.D., and Eledi, J.A. 2015. As the city grows, where do the farmers go?: Understanding Peri-urbanization and food systems in Ghana - Evidence from the Tamale Metropolis. *Urban Forum* 26(4): 443–465.

Laube, W., Awo, M., and Schraven, B. 2008. *Erratic rains and erratic markets. Environmental change, economic globalisation and the expansion of shallow groundwater irrigation in West Africa*. ZEF Working Paper Series 30. Bonn.

Lix, L.M., Keselman, J.C., and Keselman, H.J. 1996. Consequences of assumption violations revisited: A quantitative review of alternatives to the one-way analysis of variance "F" test. *Review of Educational Research* 66(4): 579–619.

Marenya, P.P., and Barrett, C.B. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy* 32(4): 515–536.

Mashavave, T., Mapfumo, P., Mtambanengwe, F., Gwandu, T., and Siziba, S. 2013. Interaction patterns determining improved information and knowledge sharing among smallholder farmers. *African Journal of Agricultural and Resource Economics* 8(1): 1–12.

Matuschke, I., and Qaim, M. 2009. The impact of social networks on hybrid seed adoption in India. *Agricultural Economics* 40(5): 493–505.

Matuschke, I. 2008. Evaluating the impact of social networks in rural innovation systems. An Overview.https://www.ifpri.org/publication/evaluating-impact-social-networks-rural-innovation-systems. Accessed 7 January 2014.

Mireri, P.C. 2013. Assessment of the contribution of urban agriculture to employment, income and food security in Kenya: A case of Kisumu municipality. *African Journal of Agricultural Research* 8(23): 2884–2896.

Moebius-Clune, B.N., van Es, H.M., Idowu, O.J., Schindelbeck, R.R., Kimetu, J.M., Ngoze, S., Lehmann, J., and Kinyangi, J.M. 2011. Long-term soil quality degradation along a cultivation chronosequence in western Kenya. *Agriculture, Ecosystems and Environment* 141(1-2): 86–99.

Ngetich, J.K. 2013. Planning and development of Kakamega county in Kenya: Challenges and opportunities. *Research Journal in Organizational Psychology and Educational Studies* 2(3): 111–118.

Nyantakyi-Frimpong, H., and Kerr, R.B. 2014. A political ecology of high-input agriculture in northern Ghana. *African Geographical Review* 34(1): 13–35.

Ochieng, C.M.O. 2007. Development through positive deviance and its implications for economic policy making and public administration in Africa: The case of Kenyan agricultural development, 1930–2005. *World Development* 35(3): 454–479.

Odendo, M., Obare, G., and Salasya, B. 2009. Factors responsible for differences in uptake of integrated soil fertility management practices amongst smallholders in western Kenya. *African Journal of Agricultural Research* 4(11): 1303–1311.

Ortiz, O., Frias, G., Ho, R., Cisneros, H., Nelson, R., Castillo, R., Orrego, R., Pradel, W., Alcazar, J., and Bazán, M. 2008. Organizational learning through participatory research: CIP and CARE in Peru. *Agriculture and Human Values* 25(3): 419–431.

Otiso, K.M., and Owusu, G. 2008. Comparative urbanization in Ghana and Kenya in time and space. *GeoJournal* 71(2-3): 143–157.

Pamuk, H., Bulte, E., and Adekunle, A.A. 2014. Do decentralized innovation systems promote agricultural technology adoption?: Experimental evidence from Africa. *Food Policy* 44: 227–236.

Pascucci, S., and De-Magistris, T. 2011. The effects of changing regional Agricultural Knowledge and Innovation System on Italian farmers' strategies. *Agricultural Systems* 104(9): 746–754.

Prell, C., Reed, M., Racin, L., and Hubacek, K. 2010. Competing structure, competing views: The role of formal and informal social structures in shaping stakeholder perceptions. *Ecology and Society* 15(4): 34–41.

Pretty, J., Camilla, T. and Stella, W. 2011. Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability* 9(1): 5–24.

Reagans, R., and McEvily, B. 2003. Network structure and knowledge transfer: The effects of cohesion and range. *Administrative Science Quarterly* 48(2): 240–267.

Röling, N. 2010. The impact of agricultural research: evidence from West Africa. *Development in Practice* 20(8): 959–971.

Röling, N. 2009a. Conceptual and methodological developments in innovation. In *Innovation Africa: Enriching farmers' livelihoods*, ed. Sanginga, P.C., Waters-Bayer, A., Kaaria, S., Njuki, J., and Wettasinha, C. 9–34. London, UK: Earthscan.

Röling, N. 2009b. Pathways for impact: Scientists' different perspectives on agricultural innovation. *International Journal of Agricultural Sustainability* 7 (2): 83–94.

Röling, N. 1990. The agricultural research-technology transfer interface: A knowledge systems perspective. In *Making the link: Agricultural research and technology transfer in developing countries*, ed. D. Kaimowitz, 1–42. Boulder, Colorado: Westview Press.

Rost, K. 2011. The strength of strong ties in the creation of innovation. *Research Policy* 40(4): 588–604.

Rycroft, R.W. 2007. Does cooperation absorb complexity?: Innovation networks and the speed and spread of complex technological innovation. *Technological Forecasting and Social Change* 74(5): 565–578.

Sanginga, N., and Woomer, P.L. 2009. *Integrated soil fertility management in Africa: Principles, practices and developmental process.* Nairobi: TSBF-CIAT.

Schareika, N. 2014. The social nature of environmental knowledge among the nomadic Woɗaaɓe of Niger. *Ecology and Society* 19(4): 42–55.

Schut, M., van Asten, P., Okafor, C., Hicintuka, C., Mapatano, S., Nabahungu, N.L., Kagabo, D., Muchunguzi, P., Njukwe, E., Dontsop-Nguezet, P.M., Sartas, M., and Vanlauwe, B. 2016. Sustainable intensification of agricultural systems in the Central African Highlands: The need for institutional innovation. *Agricultural Systems* 145: 165–176.

Smaling, E.M.A. 1993. An agro-ecological framework for integrated nutrient management with special reference to Kenya. Doctoral dissertation. Wageningen: Wageningen Univeristy

Spielman, D.J., Kristin, D., Martha, N., and Gezahegn, A. 2011. Rural innovation systems and networks: Findings from a study of Ethiopian smallholders. *Agriculture and Human Values* 28(2): 195–212.

Spielman, D.J., Ekboir, J., and Davis, K. 2009. The art and science of innovation systems inquiry: Applications to Sub-Saharan African agriculture. *Technology in Society* 31(4): 399–405.

Stoorvogel, J.J., Smaling, E.M.A., and Janssen, B.H. 1993. Calculating soil nutrient balances in Africa at different scales. *Fertilizer Research* 35(3): 227–235.

Thuo, M., Bell, A.A., Bravo-Ureta, B.E., Okello, D.K., Okoko, E.N., Kidula, N.L., Deom, C.M., and Puppala, N. 2013. Social network structures among groundnut farmers. *Agriculture and Human Values* 19(4): 339–359.

Tittonell, P., and Giller, K.E. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research* 143: 76–90.

Tittonell, P., Misiko, M., and Ekise, I. 2008. Talking soil science with farmers. *Leisa-Leusden* 24(2): 15–17.

Valente, T.W. 1996. Social network thresholds in the diffusion of innovations. *Social Networks* 18: 69–89.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L., and Sanginga, N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture* 39(1): 17–24.

Vanlauwe, B., Rotich, E., Okalebo, R., Bationo, A., Mukalama, J., Ekise, I., Ndufa, J., and Cadisch, G. 2004. Integrated soil integrated soil fertility management in practice in western Kenya. The comminutor. Nairobi.

Warren, G.P., Atwal, S.S., and Irungu, J.W. 1997. Soil nitrate variations under grass, sorghum and bare fallow in semi-arid Kenya. *Experimental Agriculture* 33(3): 321–333.

Wilcox, R. 1987. New designs in analysis of variance. *Annual Review of Psychology* 38(1): 29–60.

Williams, G. 2003. Studying development and explaining policies. *Oxford Development Studies* 31(1): 37–58.

Williams, P. 2002. The competent boundary spanner. *Public Administration* 80(1): 103–124.

Wolf, S., Just, D., and Zilberman, D. 2001. Between data and decisions: The organization of agricultural economic information systems. *Research Policy* 30: 121–141.

Yiridoe, E.K., Langyintuo, A.S., and Dogbe, W. 2006. Economics of the impact of alternative rice cropping systems on subsistence farming: Whole-farm analysis in northern Ghana. *Agricultural Systems* 91(1-2): 102–121.

3 Understanding system innovation adoption: A comparative analysis of integrated soil fertility management uptake in Tamale (Ghana) and Kakamega (Kenya)

Ivan S. Adolwa[1], Stefan Schwarze[2*], Boaz Waswa[3] and Andreas Buerkert[1]

[1]Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, Steinstr. 19, Universität Kassel, D-37213 Witzenhausen, Germany;

[2]Department of Agricultural Economics and Rural Development, Georg-August-Universität Göttingen, Platz der Göttinger Sieben 5, D-37073 Göttingen, Germany;

[3]International Centre for Tropical Agriculture (CIAT), ICIPE Duduville Campus, Kasarani, P.O. Box 823-00621, Nairobi, Kenya.

*Corresponding author: s.schwarze@agr.uni-goettingen.de

3.1 Abstract

Sustainable intensification for improved productivity in African farming systems has been high on the agenda of research and development programs for decades. System innovations such as integrated soil fertility management (ISFM) and conservation agriculture have been proposed to tackle the complex challenges farmers face. In this study, we assess how different factors at the plot, farm and institutional level influence the adoption of ISFM. We employed a stratified sampling approach to randomly select 285 and 300 farmers in Tamale, northern Ghana, and Kakamega County, western Kenya, respectively. These two sites were selected to understand the underlying reasons for their divergent adoption levels. Ordinal regression models were used to identify determinants of adoption. In Tamale adoption rates of ISFM are very low. Just 8% of the farmers partially and 3% fully adopted the recommended practices. The adoption rates are much higher in Kakamega, where 44% of the farmers partially and 36% fully adopted ISFM. The low availability of improved seeds is a major reason for the low adoption rates in Tamale. Moreover, plot level variables such as soil carbon, clay content and pH had a significant effect on adoption at both sites. Among farm and household characteristics, number of adults, off-farm occupation, education, age of household head and livestock ownership significantly affected integrated soil fertility management adoption. Key policy recommendations include improved access to credit for both sites as well as enhanced access to improved seeds in Tamale.

Keywords: Complete adoption; Integrated Soil Fertility Management (ISFM); Partial adoption; Sustainable intensification; System innovations

3.2 Introduction

Rapid population growth in Sub-Saharan Africa (SSA) has challenged efforts for sustained growth in agricultural productivity of smallholder agriculture. Although net agricultural production in SSA has been growing since 1960, population growth has led to declines in per capita production by 21% in East Africa, 40% in Central Africa and 22% in southern Africa and an only 10% increase in West Africa (Pretty et al. 2011). As further area expansion is hardly possible and fertility of agricultural soils is very limited due to strong weathering, the need to sustainably enhance crop and livestock production is even more pressing (Pretty et al. 2011; Vanlauwe et al. 2015). System innovations unlike single technologies such as fertilizer application or the use of new high yielding crop varieties, are integrated packages that often combine several synergistic agronomic and management components to improve crop productivity and environmental resilience (Noltze et al. 2012). These innovations have the potential to improve food security in developing countries as they emphasize on sustainability that cuts across the ecological, economic, social and cultural realms (Flora 2010). System innovations are thus critical for sustainable intensification. Following this definition Integrated Soil Fertility Management (ISFM) is claimed to maintain or even enhance soil fertility whilst fostering ecological resilience in an economically profitable and environmentally friendly manner (Vanlauwe et al. 2010; Vanlauwe et al. 2015).

Despite great efforts of public and private actors for wide-scale dissemination, the uptake of system innovations by farmers has been disappointing and partial adoption is common (Giller et al. 2006; Wollni et al. 2010). Constraints on system innovation adoption at the farm and household level are documented in numerous studies (Marenya and Barrett 2007; Odendo et al. 2009; Odendo et al. 2010; Jaleta et al. 2013; Teklewold et al. 2013), but analyses on plot level constraints including soil fertility parameters determining potential yields are still scarce. In this context, Noltze et al. (2012) showed that soil texture had a significant effect on the adoption of the system of rice intensification (SRI) in Timor Leste. To the best of our knowledge such an analysis has not yet been done for ISFM. Corbeels et al. (2014) in their multi-scale analysis also argued that parameters drawn from different scales of analysis, including soil fertility and yield indicators, could be determinants of conservation agriculture (CA) adoption. Given the heterogeneous nature of African soils (Tittonell et al. 2005; Vanlauwe et al. 2007), we hypothesized that soil fertility indicators may have an influence on ISFM adoption. Apart from plot level factors, it was important to control for known drivers of system innovation adoption. These included labor availability, information access, association membership, formal education and off-farm income. This study hence seeks to contribute to the understanding of how factors at the plot, household, farm and institutional level may hinder or promote the adoption of ISFM. The study uses data from two sites located in East and West Africa that differ in adoption levels.

3.3 ISFM: Definition and historical background

ISFM is a soil fertility management paradigm developed in an effort to counteract the increasingly alarming rate of soil fertility decline in Africa. As such ISFM has been defined as a set of soil fertility management practices that include the use of mineral fertilizers, organic soil amendments and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions to maximize agronomic use efficiency of the applied nutrients and improve crop productivity (Vanlauwe et al. 2010). The paradigms underpinning soil fertility management in SSA have changed substantially in the past five decades (Sanginga and Woomer 2009; Kolawole 2013). In the 1960s and 1970s greater emphasis was placed on fertilizer use with little regard to organic amendments, which in due course became unsustainable due to infrastructural weaknesses and in some cases soil organic matter decline and soil erosion. In the 1980s organic resource use became the focal point of soil fertility management but this also failed due to labor and land constraints as well as scarcity of organic amendments in view of their multiple competitive uses. The beginning of the 1990s fostered the concept of integrated natural resource management (INRM) entailing the combination of mineral fertilizers and organic amendments. This culminated in the conceptualization of the ISFM paradigm in the 2000s with the recognition that organic resources can improve use efficiency of fertilizers whereby nutrient management strategies were to be adapted to local conditions. It is worth noting that with ISFM the use of mineral fertilizers is the major entry point to increased yields from which vital organic resources may be derived (Sanginga and Woomer 2009).

Current practice of farmers has often been characterized by use of traditional seed varieties receiving too little and sub-optimally managed inputs (Sanginga and Woomer 2009; Vanlauwe et al. 2010). When soils are responsive, fertilizers and improved germplasm could be suitable entry points (Vanlauwe and Zingore 2011). Where soils are less responsive a substantial boost by organic input application is required for increase in agronomic efficiency (AE) as the application of mineral fertilizers and improved germplasm alone are insufficient (Vanlauwe et al. 2010; Vanlauwe et al. 2015). There may be, however, several constraints that need to be addressed through local adaptation. These include soil acidity, drought or moisture stress, hard pan formation and destruction of the soil structure caused by soil erosion (Vanlauwe et al. 2015). To address soil acidity, application of lime may be necessary (Kisinyo et al. 2014; Vanlauwe et al. 2015). Drought stress can be alleviated using water harvesting techniques such as tied ridges (Kihara et al. 2011), whereas on hillsides soil erosion control should be implemented (Vanlauwe et al. 2010). At farm scale, farmers take decisions on where to allocate available resources such as labor and capital within their heterogeneous farms and in line with adapting to within-farm soil fertility gradients (Vanlauwe et al. 2015). Core aspects of the ISFM paradigm entail a maximization of on-farm recycling, improving efficiency of external inputs, and integrating scientific knowledge with indigenous knowledge in order to enable sustainable intensification (Tittonell et al. 2008a).

3.4 Materials and methods

3.4.1 Identifying determinants of adoption

Often system technologies are adopted partially, that is, only some of the components are applied by the farmer. Sequential adoption of such technologies has been estimated previously using different models e.g. multivariate bayesian (Aldana et al. 2011) or ordered probit (Wollni et al. 2010) models. ISFM adoption, in particular, has previously been estimated as a binomial process where it is either adopted or not adopted (Mugwe et al. 2009; Odendo et al. 2009; Adolwa et al. 2012) or as a correlated binomial process of discrete choices (Marenya and Barrett 2007). However, in our case we observe a step-wise cumulative adoption of the technologies. An ordinal regression model (ORM), unlike a poisson estimator, is appropriate for this estimation as the probability of the farmer selecting the first step of adoption is not the same as selecting the second or third step given that utilization of the latter steps requires the farmer to have gained in knowledge.

According to Long and Freese (2001) the ORM is given as:

$$y_i^* = X_i\beta + \varepsilon_i, \quad (1)$$

where y^* is the latent variable for farmer i, ε_i is the random error, X_i is a vector of independent variables, and β represents the parameters to be estimated. The measurement model divides y^* into J ordinal categories:

$$y_i = m \text{ if } T_m - 1 \le y_i^* < T_m \text{ for } m = 1 \text{ to } J, \tag{2}$$

where the cut-points T_1 through T_{J-1} are estimated with the assumption that $T_0 = -\infty$ and $T_J = \infty$. In our case, the observed independent categories are tied to the latent variable by the measurement model:

$$y_i = \begin{cases} 1 \rightarrow no\ adoption & if\ T_0 = -\infty \le y_i^* < T_1 \\ 2 \rightarrow partial\ adoption\ 1 & if\ T_1 \le y_i^* < T_2 \\ 3 \rightarrow partial\ adoption\ 2 & if\ T_2 \le y_i^* < T_3 \\ 4 \rightarrow complete\ adoption & if\ T_3 \le y_i^* < T_4 = \infty \end{cases} \tag{3}$$

For a given value of x the probability of an observed outcome is given as:

$$\Pr(y = m|\, \text{x}) = \Pr(T_{m-1} \le y^* < T_m|\text{x}) \tag{4}$$

As shown in equation 4, the probability of observing $y = m$ for a given value of x relates to the region of the distribution where y^* falls between the cut-points T_{m-1} and T_m. If y^* is substituted with $X\beta + \varepsilon$ then the predicted probability in the ORM becomes:

$$\Pr(y = m|\, \text{x}) = F(T_m - \text{X}\beta) - F(T_{m-1} - \text{X}\beta), \tag{5}$$

where F is the cumulative distribution function (cdf) for ε. Since we estimate an ordinal logit model, F is logistic with Var $(\varepsilon) = \pi^2/3$. Equation 5 can thus be simplified to:

$$\Pr \le = F(T_m - \text{X}\beta) \text{ for } m = 1 \text{ to } J - 1 \tag{6}$$

Equation 6 can be used to compute cumulative probabilities for the ORM, which is equivalent to $J - 1$ binary regressions assuming that the slope coefficients *(β)* are identical across each regression. This important assumption for the ORM is known as the parallel regression or proportional odds assumption (Long and Freese 2001). The Stata command “omodel” developed by Wolfe and Gould (1998) was used to test this assumption by means of an approximate likelihood-ratio test.

A major drawback of the ordinal logistic regression is that it is very restrictive (Long and Freese 2001; Williams 2006). It is common for some β’s to differ across values of J resulting in the violation of the parallel regression assumption. The partial proportional odds model overcomes these restrictions by allowing some β coefficients to be the same for all values of J, whereas others can differ (Williams 2006). The model is given as:

$$P(Y_i > J) = \frac{\exp(\alpha_j X1_i\beta1 + X2_i\beta2 + X3_i\beta3_j)}{1 + \{exp(\alpha_j + X1_i\beta1 + X2_i\beta2 + X3_i\beta3_j)\}}, \qquad J = 1,2, \ldots\ldots, m-1 \tag{7}$$

In the equation above the β’s for $X1$ and $X2$ are the same for all categories J while those of $X3$ are allowed to differ. The parallel-lines model was deemed suitable for Tamale as the assumption of the proportional odds model was met, whereas the partial proportional odds model was preferred for Kakamega as this assumption was violated. Given that there were four adoption categories, a series of logistic regression models were produced in Kakamega’s case: no adoption versus partial adoption 1 (fertilizer + improved germplasm) or partial adoption 2 (fertilizer + improved germplasm + organic amendments) or complete adoption entailing a local adaptation measure in addition to the preceding practices; no adoption or partial adoption 1 versus partial adoption 2 or complete adoption; and no adoption or partial adoption 1 or partial adoption 2 versus complete adoption. If the variables met the proportional odds assumption their parameter estimates would be identical in the three models combined into a single model. Otherwise, three different estimates would be shown for three unique models. The model was implemented in Stata using the gologit2 (Williams 2006) command.

3.4.2 The study sites

The study was conducted in Tamale, Ghana and Kakamega, Kenya (Figure 13). Both sites are located in the moist savanna and woodland zone that includes the Guinea Savanna of West Africa and East Africa’s Highland Mosaic (Sanginga and Woomer 2009).

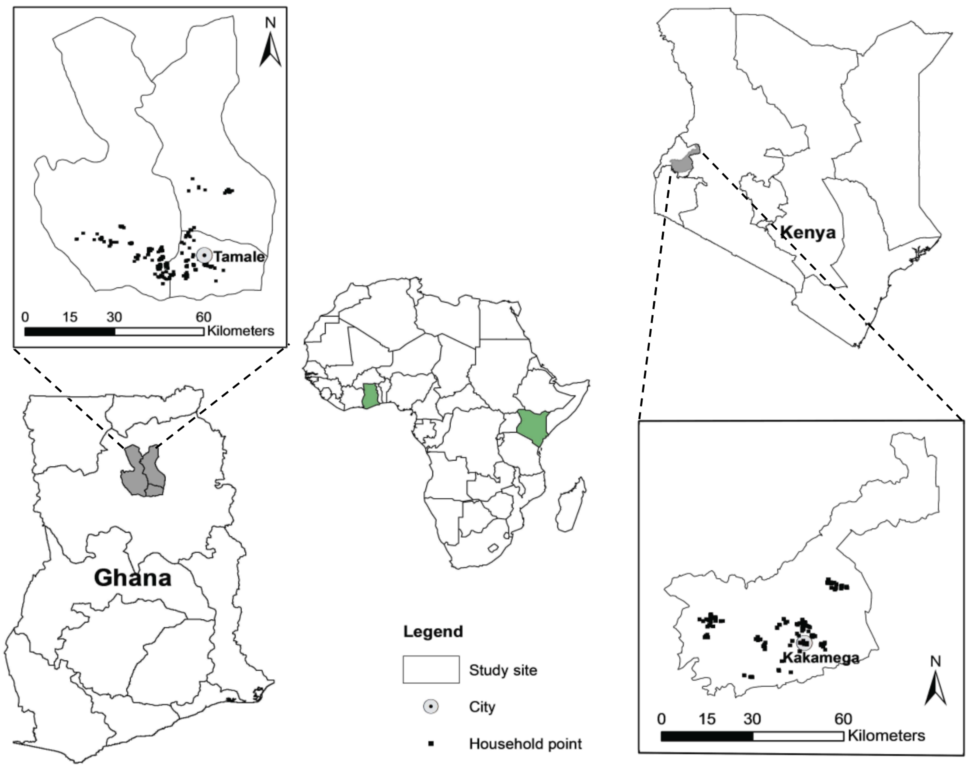

Figure 13 Maps highlighting the two study regions Tamale, Ghana and Kakamega, Kenya.

Tamale is a rapidly growing agglomeration and is considered the fastest growing city in West Africa (Gyasi et al. 2014). It is Ghana's third largest city and the capital of its northern region. Agricultural production is dominated by vegetable production in backyards and open spaces within city confines. However, cereal cultivation, particularly maize (*Zea mays L.*) cultivation is still common even within the urban areas. Maize is a major staple crop in Tamale and Kakamega and constitutes a large share of the dietary intake of the local communities (Odendo et al. 2007; Chagomoka et al. 2016). At the fringes of the city, beyond a 3 km radius from the centre, peri-urban agriculture is dominated by cultivation of cereals e.g. maize and rice (*Oryza sativa* or *Oryza glaberrima*), tuber crops, and vegetables. The rural areas surrounding the city have predominantly cereal-based cropping systems with maize as the dominant crop. Groundnut (*Arachis hypogaea*) is the most common legume. Other crops grown include yams (*Dioscorea* spp.), cowpea (*Vigna unguiculata*) and vegetables that are mostly grown along field edges. Tamale receives an annual rainfall of about 1100 mm which is uni-modally distributed. Although the landscape is flat, sheet erosion is common due to limited tree cover. The average altitude is 183 m above sea level (asl). ISFM activities in the study area have been carried out by organizations such as the Savanna Agricultural Research Institute (SARI) for the past four years but mainly concentrated on the rural areas.

Kakamega County is one of the administrative units of Kenya and consists of several urban centers including Kakamega town (the headquarters of the county). The rest of the county is predominantly rural. In the towns mainly vegetables such as cabbage (*Brasssica oleracea*), cowpea and kales (*Brassica oleracea*) are grown. Other crops common in urban and peri-urban areas include bananas, beans (*Phaseolus vulgaris*) and maize. In the rural areas, maize is the dominant staple grown mainly for subsistence. Cash crops are also grown alongside maize; in the wetter zone tea (*Camellia sinensis*) is grown whereas in the less humid zone sugarcane (*Saccharum officinarum*) is the main cash crop. Cereal-legume intercropping systems dominate the area with maize-bean systems being the most common. Due to extensive ISFM activities over the last ten years soybeans (*Glycine max*), which have a high potential for value addition, have gradually been incorporated in the cropping systems. Kakamega receives as much as 2000 mm of rainfall per annum in a bi-modal pattern. Therefore, most farmers take advantage of this to crop twice per year. The landscape is steep in some areas and average altitude is 1535 m asl.

3.4.3 Data collection: Survey and laboratory analysis

Data were collected in a household survey between July 2014 and February 2015. To select respondents, a stratified random sampling approach was utilized at both sites. Farming households were stratified into participants in ISFM activities and non-participants. Participant farmers were randomly selected from lists of participating farmers, which were compiled with the assistance of extension officers, local research institutions, village elders and lead farmers that had been involved in disseminating ISFM activities. Non-participants were randomly selected from a list of farmers, which was obtained from the UFP project in Tamale (Bellwood-Howard et al. 2015) and from the Agricultural Sector Development Support Programme of Kenya in Kakamega (Agricultural Sector Development Support Programme 2014). In this way a total of 285 farmers were selected in Tamale but information from three farmers was not utilized for analysis due to missing data. In Kakamega, a total of 300 farmers were selected, but one farmer had to be dropped because his soil samples got lost. Face-to-face interviews using a structured questionnaire were conducted. The questionnaire contained sections on socio-demographic characteristics of household members, farm characteristics, crop production and management, as well as off-farm activities. The reference period for all economic activities comprised the last twelve months prior to the interview.

In addition, soil samples (0-20 cm depth) were drawn from 322 and 459 maize plots belonging to farmers interviewed in Tamale and Kakamega, respectively. Some of these maize plots were closer to their homesteads (in-fields) whereas others were further away (out-fields). These samples were taken to capture information on soil fertility indicators influencing ISFM uptake at the plot level. Farmers often use local soil quality indicators such as tilth (or the ‘feel’ of the soil), soil color, productivity in terms of crop yield, vigor of growth or intensity of leaf color and the presence of soil fauna (Barrios et al. 2006; Mairura et al. 2007). Therefore, we deemed it appropriate to collect data on technical indicators such as soil organic carbon (SOC), total C, total nitrogen (N), available phosphorus (P), pH, and soil texture (% clay, % sand, % silt) that may mirror these indigenous criteria. To this end, three to five sub-samples were collected from each maize field cultivated (as long as it was accessible) in the previous season. These sub-samples, mixed to form a composite sample, were immediately air-dried and sieved to 2-mm. Subsequently, a subsample of the soil (about 10%) was subjected to laboratory analysis: SOC (Walkley-Black method), available P as Bray-P, pH water (2.5:1 water), and soil texture were determined according to Okalebo et al. (1993). Elemental analysis (combustion method) was used to determine total N and C after grinding samples to 0.5 mm. The FLASH 2000 Organic Elemental Analyzer Thermo Scientific (Thermo Fisher Scientific Inc. Waltham, MA, USA) was used for this purpose. This instrument allows rapid, precise and environmental-friendly determinations of C, N and sulphur in soils and other materials (Jimenez and Ladha 1993). The dry combustion used by this instrument provides more reliable data of SOC than the Walkley-Black method (Terhoeven-Urselmans et al. 2010). Unused portions of the samples were subjected to mid infra-red (MIR) analysis. Non-destructive infra-red spectroscopy (NIRS) methods offer a quick, efficient, accurate and cost-efficient means of analyzing large numbers of soil samples (Viscarra Rossel et al. 2006). The instrument used for analysis was a TENSOR 27 HTS-XT (Bruker Co., Billerica, MA, USA) mid-infrared (MIR) spectrometer. This instrument captured MIR spectral data using the HTS-XT diffuse reflectance method with spectral measurement ranging between 4000–400 cm^{-1} with 4 cm^{-1} resolution (3578 data points). Each sample was loaded onto an aluminium microtitre plate, which has 96 wells or shallow holes, in two replicates. Two spectra from each sample were averaged before calibration and analysis. For principal components analysis (PCA) and partial least-squares regression, about 90% of the MIR spectra were chosen for calibration and the remaining 10% were used for validation. Partial least-squares regression was carried out on the calibration set with reference values obtained from the conventional soil analysis. Following Terhoeven-Urselmans et al. (2010), prediction performance was determined using the coefficient of determination (r^2) of the linear regression of predicted against measured values, the root mean square errors of calibration (RMSEC), and the root mean square errors of prediction (RMSEP).

Hereby RMSEC is computed as

$$\text{RMSEC} = \sqrt{\frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N-A-1}}, \qquad (8)$$

where *A* is the number of principal components used in the model.
In general, good predictions have an $r^2 \geq 0.75$, whereas satisfactory predictions have an r^2 of 0.65 to 0.74 (Shepherd and Walsh 2002; Terhoeven-Urselmans et al. 2010). R software was used to conduct PCA and partial least-squares regression, which were in turn utilized to generate predicted values for the soil variables. However, total N, total C (for Kakamega) as well as sand and silt content were not included in the ORM due to collinearity of data.

3.5 Results and discussion

3.5.1 Prediction of soil data using calibration models

Predictions for available P, pH, total C and N were good for Tamale soils whereas soil texture predictions were mixed (Figure 14). Predicted values for soil texture were thus readjusted using the more reliable values of sand and silt. Janik et al. (1998) have suggested that large residuals may arise as a result of errors in the primary laboratory method rather than the spectroscopy method. For Kakamega, all soil parameter predictions had an $r^2 > 0.75$ (Figure 15).

3.5.2 Descriptive results

Table 11 shows the adoption of ISFM for the two study sites. Complete ISFM adoption entails adopting all three components of ISFM, while partial adoption refers to using one and two components. In Tamale only 11% of farmers' plots entailed either partial or complete set of ISFM practices compared with 80% in Kakamega. The extremely low adoption in Tamale could be attributed to the unavailability of improved seeds. The adoption of the second component is quite low at both sites. Manure and compost are the most preferred organic amendments in the study areas, but these are often scarce and are labor-demanding (Schlecht et al. 2007). Hence, in some cases local adaptation measures such as crop residue use may be easier to implement.

Table 11. Adoption of ISFM components at plot level

No. of components	Description	Tamale (%)	Kakamega (%)
0	Current practice-traditional varieties and/or no fertilizer	88.82	19.61
1	Improved germplasm + fertilizer	5.28	35.73
2	Improved germplasm + fertilizer + organic amendments	3.11	8.28
3	Improved germplasm + fertilizer + organic amendments + local adaptation (uses lime, targeted manure application, crop residues or mulch, constructed terraces, tied ridges or ridging)	2.79	36.38

Descriptive statistics for both sites are summarized in Table 12. ISFM farmers are defined as farmers who have either partially or completely adopted ISFM. In Tamale, ISFM households on one hand, have more livestock, spent a longer time in school and are more likely to live in urban/peri-urban areas as compared to its rural surroundings. Likewise, there are more ISFM farmers involved in off-farm activities. On the other hand, non-ISFM farmers have larger households and higher membership in farmer associations. At the plot level, maize fields of ISFM farmers tend to be closer to the homestead while maize fields of non-ISFM farmers have more silt. In Kakamega, ISFM adopters spent more years in school and a higher share live in urban/peri-urban areas. They have larger households and thus more family labor (Table 12). Similarly, more ISFM farmers are engaged in off-farm activities. At the plot level, maize fields of non-ISFM farmers have higher available P and overall pH is quite low.

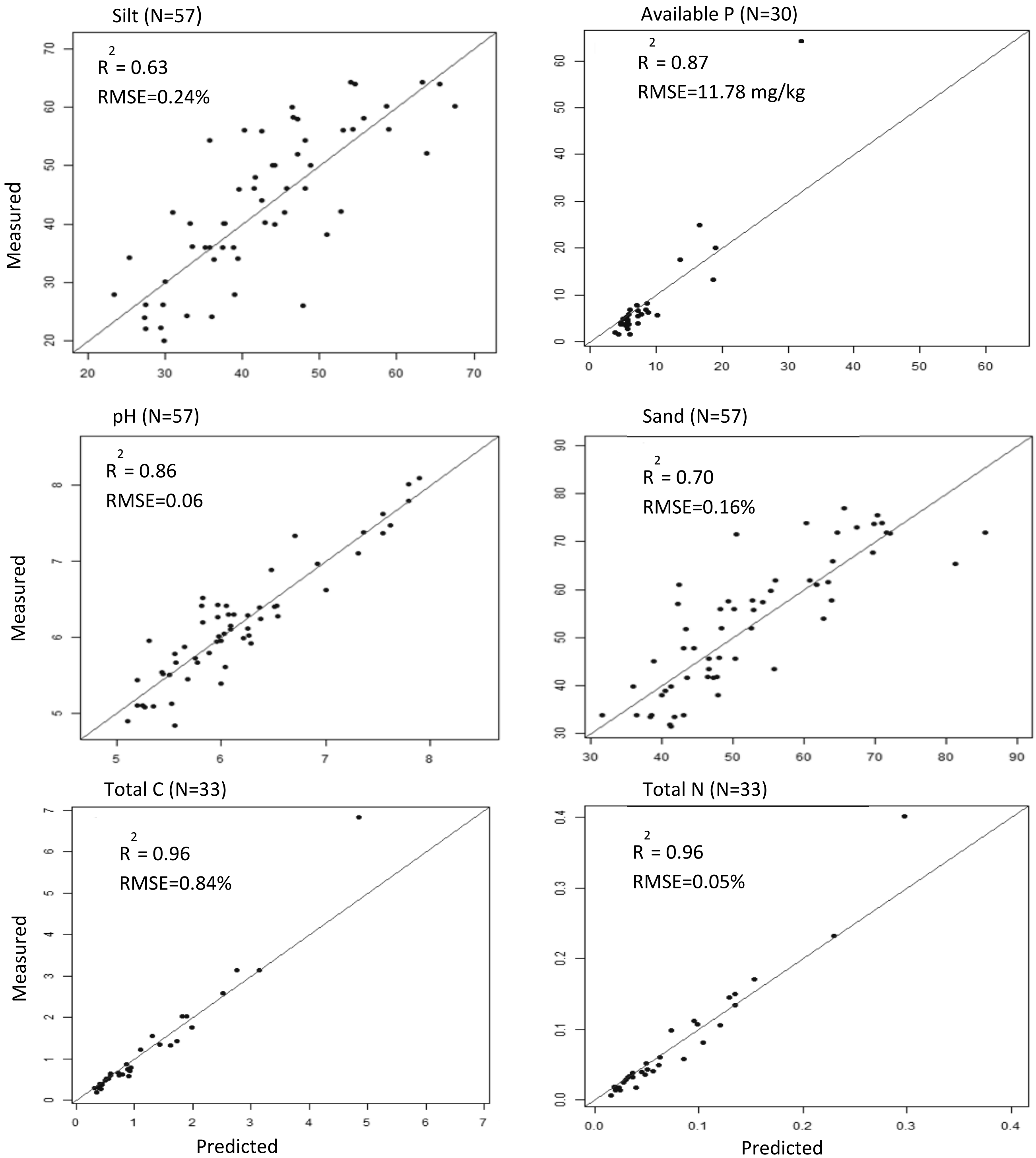

Figure 14 Calibration models for key parameters from the topsoil of farmers' maize fields in Tamale, Ghana. RMSE=Root Mean Square Error

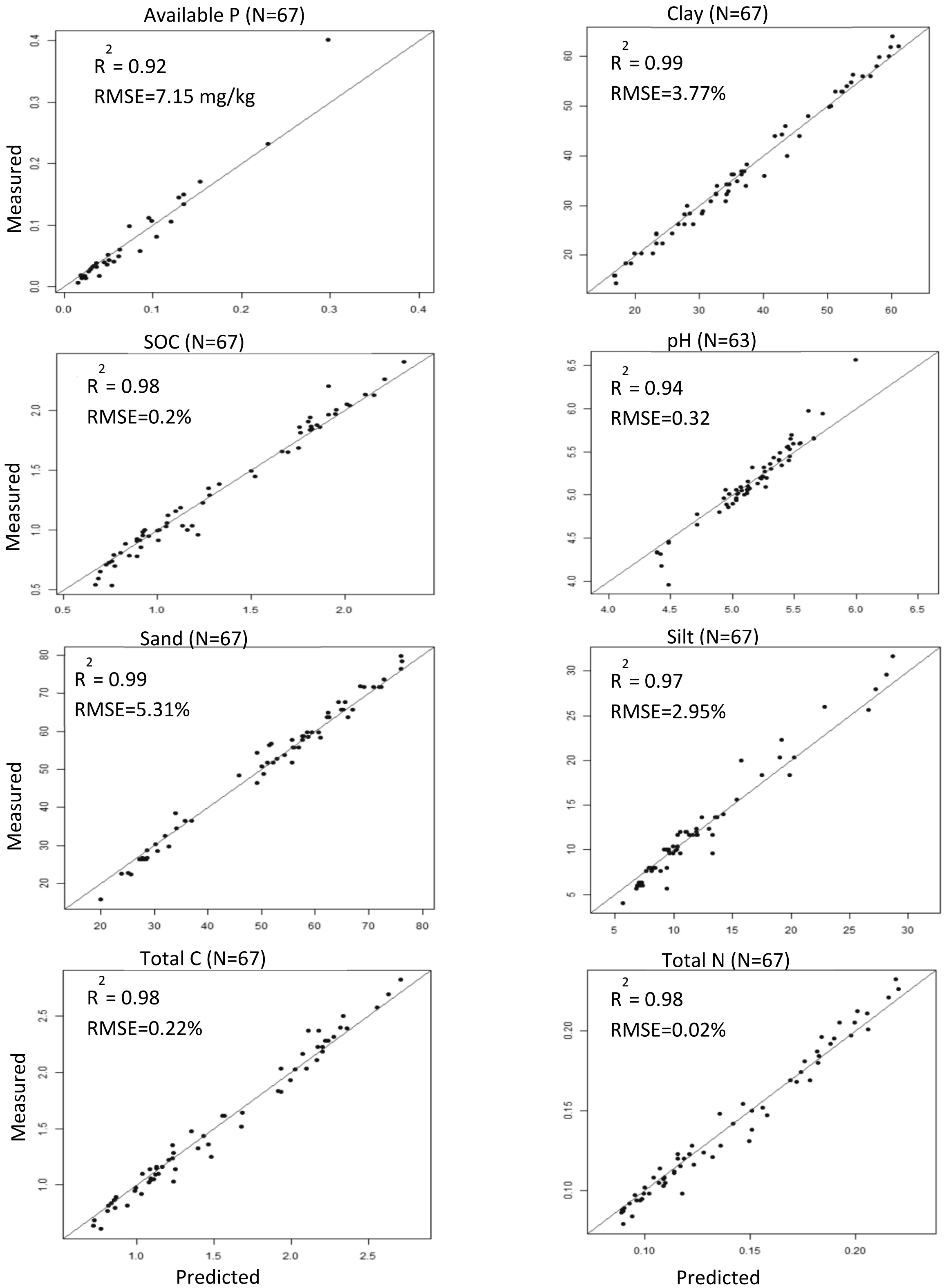

Figure 15 Calibration models for key parameters from the topsoil of farmers' maize fields in Kakamega, Kenya. RMSE=Root Mean Square Error

Table 12 Descriptive statistics of adopters and non-adopters of ISFM in Tamale (Ghana) and Kakamega (Kenya)

	Tamale Means (SD)						Kakamega Means (SD)					
	All		ISFM		Non-ISFM		All		ISFM		Non-ISFM	
Household level characteristics												
Farm and location characteristics												
Total area cultivated (acres)	7.60	(8.74)	7.81	(9.45)	7.57	(8.63)	2.52	(4.75)	2.62	(5.02)	1.90	(2.41)*
Total maize area cultivated (acres)	3.86	(3.87)	4.32	(5.44)	3.78	(3.55)	1.31	(1.36)	1.35	(1.36)	1.08	(1.29)
Tropical livestock units[a]	3.81	(7.21)	6.15	(15.11)	3.42	(4.72)**	2.20	(2.06)	2.22	(2.07)	2.04	(2.03)
HH in urban/peri-urban area (%)	28.00	(44.80)	61.00	(49.30)	22.00	(41.60)***	21.00	(40.60)	22.00	(41.80)	10.00	(29.60)**
Household and social capital variables												
Age of HH head (years)	52.52	(13.59)	51.09	(16.03)	52.76	(13.15)	53.35	(12.90)	53.38	(12.88)	53.16	(13.13)
HH head education (years)	2.26	(4.90)	5.63	(6.10)	1.70	(4.44)***	9.02	(3.93)	9.18	(3.81)	7.95	(4.48)**
HH size (no.)	13.37	(7.28)	11.22	(6.62)	13.73	(7.33)**	7.68	(3.80)	7.88	(3.88)	6.41	(2.98)***
Adult members of HH (no.)	4.29	(2.67)	3.98	(2.33)	4.34	(2.72)	4.25	(2.21)	4.36	(2.24)	3.62	(1.95)**
HHs with off-farm occupation (%)	72.00	(45.00)	89.00	(31.50)	69.00	(46.30)***	58.00	(49.40)	62.00	(48.60)	35.00	(48.10)***
Association membership (%)	66.00	(47.50)	52.00	(50.50)	68.00	(46.70)**	70.00	(45.80)	71.00	(45.20)	62.00	(49.00)
Plot level characteristics												
Slope (0=flat, 1=medium or steep)	0.06	(0.24)	0.07	(0.25)	0.06	(0.23)	0.35	(47.60)	0.36	(0.47)	0.29	(0.46)
Location (0=outside H, 1= within H)	0.41	(0.49)	0.52	(0.51)	0.39	(0.49)*	0.82	(38.30)	0.81	(0.39)	0.87	(0.34)
pH	6.19	(0.83)	6.32	(0.78)	6.17	(0.83)	4.82	(0.38)	4.81	(0.39)	4.89	(0.32)
Sand (%)	52.33	(13.97)	55.28	(12.42)	51.84	(14.18)*	49.04	(12.16)	48.99	(11.96)	49.41	(13.47)
Clay (%)	3.78	(2.95)	3.51	(3.37)	3.82	(2.88)	38.69	(9.39)	38.72	(9.23)	38.45	(10.37)
Silt (%)	43.89	(12.49)	41.22	(11.23)	44.34	(12.65)*	12.14	(4.77)	12.77	(4.45)	12.51	(4.32)
SOC (%)	0.73	(0.77)	0.77	(0.46)	0.72	(0.82)	1.35	(0.38)	1.35	(0.38)	1.36	(0.41)
Total C (%)	0.74	(0.59)	0.80	(0.63)	0.73	(0.58)	1.55	(0.45)	1.54	(0.45)	1.57	(0.50)
Total N (%)	0.05	(0.04)	0.05	(0.04)	0.04	(0.04)	0.14	(0.03)	0.14	(0.03)	0.14	(0.04)
Available P (mg/kg)	8.38	(3.64)	8.78	(2.94)	8.32	(3.74)	9.80	(5.33)	9.61	(5.02)	10.99	(6.89)*

[a] Tropical livestock units (TLU) computed following Jahnke (1982) and Odendo et al. (2009); HH stands for household and H for homestead; *, **, *** Mean values for ISFM and Non-ISFM farmers are significantly different at 10%, 5%, and 1%, respectively.

3.5.3 Determinants of ISFM adoption

To identify the determinants of ISFM adoption, we estimate ordered logit models as described in chapter 3. In Tamale, fields with a statistically higher soil carbon belong to non-adopters of ISFM (Table 13). This may not be entirely surprising as resource-constrained farmers may opt to use less inputs on plots they perceive to be fertile (Buerkert et al. 2000; Schlecht and Buerkert 2004). A unit increase in total C increases the probability of non-adoption by 11.3%. In Kakamega, in contrast, higher soil carbon enhances ISFM adoption (Table 14). There a unit increase in SOC increases the chances of complete adoption by 27.8% (Table 14). Farmers in densely populated areas such as western Kenya tend to apply most of their organic amendments and fertilizer on closer, more fertile home gardens and infields unlike their counterparts in the less densely populated and intensely used areas of West Africa (Tittonell et al. 2008b; Giller et al. 2011). The concentration of nutrients by farmers in western Kenya could also be attributed to differences in resource endowment among heterogeneous farming households whereby resource-rich farmers continually enrich their fields with fertilizer and organic inputs (Vanlauwe et al. 2015). Thus varying intensity of land use and resource allocation strategies may be among the underlying causes for the differentiated farmer response to soil fertility in the two areas.

A higher pH tends to influence non-adoption of ISFM (Table 14). An increase of one pH unit seems to increase the likelihood of non-adoption by 17.9% (Table 4). It is well known that soil acidity is a major constraint to crop production in western Kenya (Kisinyo et al. 2014), and that low soil pH reduces the effectiveness of added fertilizer (Giller et al. 2002). This implies farmers are more likely to apply organic resources and lime on their more acidic fields in line with their resource allocation strategies that prioritize use of resources where they are most needed. Unfortunately, lime usage in the region is low and those who are aware of its benefits consider it expensive and too bulky to handle. A common alternative, particularly in the sugarcane belt of the county, is the application of filter press mud (an industrial waste available from local sugar mills). Unlike Noltze et al. (2012) who reported that adoption of SRI increased with higher soil loam content, we find that increasing clay in Kakamega reduces the probability of ISFM adoption by 0.7% (Table 14). Although it has often been reported that clay content positively correlates with soil organic matter (SOM) the actual effect of soil texture on SOM storage in tropical soils remains unclear (Feller and Beare 1997; Bruun et al. 2010).

Table 13 Results for the ordinal regression model and marginal effects (dy/dx) of ISFM adoption in Tamale, Ghana

		Number of cumulative ISFM components adopted (margins)			
		0	1	2	3
Slope (D)	0.285 (0.854)	-0.014 (0.047)	0.008 (0.028)	0.003 (0.008)	0.003 (0.010)
Plot location (D)	-0.410 (0.503)	0.018 (0.021)	-0.011 (0.013)	-0.003 (0.004)	-0.004 (0.005)
Plot size (D)	-0.176 (0.206)	0.008 (0.009)	-0.005 (0.005)	-0.001 (0.002)	-0.002 (0.002)
Clay (%)	-0.080 (0.102)	0.003 (0.005)	-0.002 (0.003)	-0.001 (0.001)	-0.001(0.001)
pH	0.714 (0.448)	-0.031(0.019)	0.019 (0.012)	0.006 (0.004)	0.007 (0.005)
Total C (%)	-2.563 (1.224)**	0.113 (0.048)**	-0.068 (0.031)**	-0.020 (0.011)*	-0.025 (0.013)*
Available P (mg/kg)	-0.006 (0.114)	-0.000 (0.005)	-0.000 (0.003)	-0.000 (0.001)	-0.000 (0.001)
Adult HH members (no.)	-0.246 (0.088)***	0.011(0.004)***	-0.007 (0.003)**	-0.002 (0.001)**	-0.002 (0.001)**
HH head age (yrs.)	0.030 (0.018)*	-0.001 (0.001)*	0.001 (0.000)*	0.000 (0.000)	0.000 (0.000)
HH head education (yrs.)	0.161 (0.040)***	-0.007 (0.002)***	0.004 (0.001)***	0.001 (0.001)**	0.002 (0.001)**
Off-farm occupation (D)	1.333 (0.623)**	-0.047 (0.019)**	0.029 (0.012)**	0.008 (0.005)*	0.010 (0.005)**
Total livestock units	0.056 (0.023)*	-0.002 (0.001)**	0.001 (0.001)**	0.000 (0.000)*	0.001 (0.000)*
Maize area (acres)	0.045 (0.063)	-0.001 (0.003)	0.001 (0.002)	0.000 (0.001)	0.000 (0.001)
Assoc. membership (D)	1.250 (0.619)**	-0.048 (0.021)**	0.029 (0.013)**	0.009 (0.005)*	0.010 (0.006)*
HH location (D)	1.647 (0.646)**	-0.108 (0.057)*	0.063 (0.034)*	0.020 (0.013)	0.025 (0.016)
Cutoff 1	7.455 (2.857)				
Cutoff 2	8.441 (2.871)				
Cutoff 3	9.051 (2.880)				
Observations	322				
Log likelihood	-120.43				

Notes: Standard errors are in parentheses. HH stands for household, D for dummy and Assoc. for association
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

At the household level, education of the household head is one of the explanatory variables that seem to significantly enhance the likelihood of ISFM adoption in Tamale but not in Kakamega (Tables 13 and 14). Knowledge-intensive technologies demand that a farmer understands the underlying complexities in the various synergies of management practices. This may require some level of formal schooling (Marenya and Barrett 2007). The size of the effect of education is, however, rather small. An additional year in school of the household head leads to a marginal increase of 0.4% in component one, 0.1% in component two, and 0.2% in component three in the likelihood of adoption. As farmers in Kakamega have generally more years of schooling than their counterparts in West Africa, education there may not be much of a factor (Table 2). Against our expectation, the coefficients for the number of household adults are negative at both sites implying likelihood of adoption decreases with the availability of labor (Tables 13 and 14). Nonetheless, under some circumstances, this may be plausible. Taruvinga et al. (2016) found that large households were less likely to adopt innovations and adaptation strategies as this would mean diverting scarce resources from more pressing concerns. Moreover, the rural marginalization of some of these households was likely to severely limit off-farm opportunities.

The models also show off-farm occupation and age of household heads are significant (Tables 13 and 14). In Tamale, having off-farm occupation increases likelihood of ISFM adoption of the first component by 2.9% (Table 13). The marginal increase for the subsequent steps is with 0.8% and 1.0% substantially lower. In Kakamega, an increase in off-farm occupation increases probability of complete adoption by 13.2% (Table 14). Off-farm activities are an important source of income for many households and our results suggest that this additional income fosters ISFM adoption. The significant positive effect of age on ISFM adoption is expected given lifelong learning experiences of farmers, although the marginal effects of increasing age (Tables 13 and 14) are rather small for partial and complete adoption in Tamale and Kakamega, respectively. Farmer associations are important for ISFM adoption both in Tamale and Kakamega and as expected the sign of the coefficient is positive (Tables 13 and 14). Membership in farmer associations increases the likelihood of fertilizer and improved seed adoption in Tamale by 2.9%. This is also likely to marginally increase the adoption of organic amendments by 0.9% and complete adoption by 1%. The effect of membership in associations is much higher in Kakamega, where the likelihood for complete adoption increases by a margin of 19.4% (Table 14).

Table 14 Results for the generalized logit model and marginal effects (dy/dx) of ISFM adoption in Kakamega, Kenya

		Number of cumulative ISFM components adopted (margins)			
		0	1	2	3
Combined model: 0 vs 1-3, 0-1 vs 2-3, 0-2 vs 3					
Slope (D)	0.223 (0.210)	-0.031 (0.029)	-0.024 (0.023)	0.004 (0.004)	0.051 (0.048)
Plot size (D)	0.186 (0.182)	-0.026 (0.026)	-0.020 (0.019)	0.004 (0.004)	0.042 (0.041)
Clay (%)	-0.150 (0.028)*	0.007 (0.004)*	0.005 (0.003)*	-0.001 (0.001)	-0.011 (0.006)*
pH	-1.278 (0.625)**	0.179 (0.088)**	0.136 (0.070)*	-0.024 (0.014)*	-0.291 (0.142)**
SOC (%)	1.222 (0.616)**	-0.172 (0.087)*	-0.130 (0.069)*	0.023 (0.014)*	0.278 (0.141)**
Available P (mg/kg)	-0.030 (0.027)	0.004 (0.004)	0.003 (0.003)	-0.001 (0.001)	-0.007 (0.006)
HH head age (yrs.)	0.015 (0.008)*	-0.002 (0.001)*	-0.002 (0.001)*	0.000 (0.000)	0.003 (0.002)*
HH head education (yrs.)	0.010 (0.028)	-0.001 (0.004)	-0.001 (0.003)	0.000 (0.001)	0.002 (0.006)
Maize area (acres)	-0.165 (0.148)	0.023 (0.021)	0.018 (0.016)	-0.003 (0.003)	-0.038 (0.034)
HH location (D)	0.538 (0.279)*	-0.075 (0.040)*	-0.057 (0.031)*	0.010 (0.006)*	0.122 (0.064)*
Unique model: 0 vs 1-3					
Plot location (D)	-0.412 (0.356)				
Adult HH members (no.)	0.102 (0.077)				
Off-farm occupation (D)	1.117 (0.277)***	-0.157 (0.038)***	0.071 (0.052)	-0.046 (0.031)	0.132 (0.057)**
Total livestock units	0.095 (0.069)				
Assoc. membership (D)	-0.058 (0.289)				
Unique model: 0-1 vs 2-3					
Plot location (D)	0.334 (0.278)	-0.058 (0.050)	-0.140 (0.069)**	0.067 (0.041)	0.015 (0.067)
Adult HH members (no.)	-0.114 (0.062)*	-0.014 (0.011)	0.042 (0.015)***	-0.002 (0.009)	-0.026 (0.015)*
Off-farm occupation (D)	0.347 (0.236)				
Total livestock units	0.230 (0.071)***	-0.013 (0.010)	-0.043 (0.014)***	0.015 (0.011)	0.042 (0.017)**
Assoc. membership (D)	0.567 (0.250)**				
Unique model: 0-2 vs 3					
Plot location (D)	0.065 (0.294)				
Adult HH members (no.)	-0.115 (0.068)*				
Off-farm occupation (D)	0.578 (0.249)**				
Total livestock units	0.183 (0.074)**				
Assoc. membership (D)	0.850 (0.276)***	0.008 (0.040)	-0.148 (0.059)**	-0.054 (0.042)	0.194 (0.062)***
Observations	459				
Log pseudolikelihood	-534.491				

Notes: Robust standard errors are in parentheses. ISFM components (0=non-adoption, 1=improved germplasm + fertilizer, 2=improved germplasm + fertilizer +organic amendments, 3=complete adoption)
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Farmer associations are the main platforms for delivery of extension messages and trainings, particularly in rural areas. They also facilitate linkages with institutions that provide farm inputs, information and credit. Farmer participation in associations has been shown to spur the uptake of system innovations (Ogunlana 2004; Noltze et al. 2012). The prominence of associations in Kakamega could be attributed to the cohesive nature of farmer groupings that has been fostered by the aspect of group liability; an innovative tool applied by various microfinance institutions e.g. One Acre Fund, operating in Kenya. The role of institutions is crucial for the successful scale-up of ISFM beyond plot-level as they are envisaged to foster enabling environments thus minimizing risks to investments in sustainable innovations (Vanlauwe et al. 2014).

The farm variable that significantly influences adoption at both sites is livestock ownership as measured in tropical livestock units (Tables 13 and 14). In Tamale, an increase of one unit of TLU increases adoption of component one and three of ISFM by 0.1% (Table 13). In Kakamega, one unit increase in TLUs enhances the probability of complete adoption by 4.2% (Table 14). Livestock ownership is apparently important for adoption of component 3, which integrates the use of manure; a major source of SOM (Schlecht et al. 2007). At both sites, farmers living in or close to urban areas are more likely to adopt ISFM (Tables 13 and 14). We consider proximity to urban centers as a suitable proxy for closeness to input and output markets. The margins for adoption of component one is 6.3% for Tamale (Table 13). Proximity to markets increases the probability of complete adoption by 12.2% for Kakamega (Table 14). Increased integration of farming households with markets is vital for ISFM uptake, particularly at the entry level that comprises the use of mineral fertilizers and new germplasm (Vanlauwe and Zingore 2011).

3.6 Conclusions and recommendations

Our results highlight the importance of plot level factors, particularly soil carbon and pH, for the analysis of ISFM adoption. Interestingly, access to fields with higher total C seems to preclude farmers from intensifying input use in Tamale. This is consistent with farmers' tendency to judiciously allocate scarce resources. In Kakamega, however, higher SOC tends to spur complete adoption.

We further find that livestock ownership is also an important driver of ISFM adoption. This result suggests that only resource-endowed farmers benefit more from ISFM innovations of which organic amendments are an integral component. In any case, supplementary use of other organic resources should be explored among which shea butter chaff, a by-product of shea butter processing from the Shea tree (*Vitellaria paradoxa*), could be a viable option at least in small scale urban gardening in Tamale.

The study also underscores the importance of farmer associations, which play an important role in exposing farmers to new ideas and concepts and linking them to relevant institutions. Market inter-linkages are crucial especially for households in remote villages. This is more relevant for Tamale where ISFM entry level inputs are hardly used mainly due to the unavailability of improved seeds in the region. Structural problems afflicting the maize seed sector in Ghana have exacerbated this situation. In an effort to correct this, a seed law (the Plant Breeders bill) has been mooted to help regulate seed breeding. However, such policy measures would be more effective if more emphasis is placed on improving distribution of improved seeds while at the same time giving consideration to prevailing politico-economic structures.

In Tamale and Kakamega farmers seem to have adequate knowledge about the fertility status of their fields. The results nevertheless show that off-farm income sources are important drivers of ISFM adoption thus income shortfalls are likely to hinder them from applying the full set of ISFM practices across their farms. In this light, governmental programs to improve access to credit could help increase the use of improved seeds and to cushion farmers against the risks associated with the adoption of system innovations. To increase complete adoption in Kakamega efforts should be made to further investigate the effectiveness of lime and how its use could be increased.

Acknowledgements

This study was partly funded within Urban Food^{plus} project (FKZ: 031A242A) sponsored by the German Federal Ministry of Education and Research (BMBF) under GlobE-Research for Global Food Supply. This paper also benefited from comparative work in the rural-urban interface within FOR2432, funded by Deutsche Forschungsgemeinschaft (DFG).We are grateful for the logistical support and advice received from the University for Development Studies (UDS), the CSIR-Soil Research Institute, the Savannah Agricultural Research Institute (SARI), and the Kenya Agricultural Research and Livestock Organisation (KARLO). We also thank the Ministry of Food and Agriculture (MoFA) officers, village elders and, last but not least, farmer participants in Kenya and Ghana for their cooperation. Finally, we gratefully acknowledge the German Academic Exchange Service (DAAD) for granting a scholarship to the first author.

References

Adolwa, I.S., Okoth, P.F., Mulwa, R.M., Esilaba, A.O., Mairura, F.S., and Nambiro, E. 2012. Analysis of communication and dissemination channels influencing the adoption of Integrated Soil Fertility Management in western Kenya. *The Journal of Agricultural Education and Extension* 18(1): 71–86.

Agricultural Sector Development Support Programme. 2014. Household baseline survey report: Kakamega County. Ministry of Agriculture, Livestock and Fisheries, Nairobi.

Aldana, U., Foltz, J.D., Barham, B.L., and Useche, P. 2011. Sequential adoption of package technologies: The dynamics of stacked trait corn adoption. *American Journal of Agricultural Economics* 93(1): 130–143.

Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Ramisch, J., Trejo, M.T., and Thomas, R.J. 2006. Indicators of soil quality: A South–South development of a methodological guide for linking local and technical knowledge. *Geoderma* 135: 248–259.

Bellwood-Howard, I., Häring, V., Karg, H., Roessler, R., Schlesinger, J., and Shakya, M. 2015. Characteristics of urban and peri-urban agriculture in West Africa. Results of an exploratory survey conducted in Tamale (Ghana) and Ouagadougou (Burkina Faso). International Water Management Institute (IWMI) Working Paper 163. Colombo.

Bruun, T.B., Elberling, B., and Christensen, B.T. 2010. Lability of soil organic carbon in tropical soils with different clay minerals. *Soil Biology and Biochemistry* 42(6): 888–895.

Buerkert, A., Bationo, A., and Dossa, K. 2000. Mechanisms of residue mulch-induced cereal growth increases in West Africa. Soil Science Society of America Journal 64(1): 346-358.

Chagomoka, T., Unger, S., Drescher, A., Glaser, R., Marschner, B., and Schlesinger, J. 2016. Food coping strategies in northern Ghana: A socio-spatial analysis along the urban–rural continuum. *Agriculture and Food Security* 5(1): 265-280.

Corbeels, M., de Graaff, J., Ndah, T.H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H.D., and Adolwa, I.S. 2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems and Environment* 187: 155–170.

Feller, C. and Beare, M.H. 1997. Physical control of soil organic matter dynamics in the tropics. *Geoderma* 79(1-4): 69–116.

Flora, C.B. 2010. Food security in the context of energy and resource depletion: Sustainable agriculture in developing countries. *Renewable Agriculture and Food Systems* 25(02): 118–128.

Giller, K.E., Cadisch, G., and Palm, C. 2002. The North-South divide!: Organic wastes, or resources for nutrient management? *Agronomie* 22(7-8): 703–709.

Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S.,Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C., and Vanlauwe, B. 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems* 104(2): 191–203.

Giller, K.E., Rowe, E.C., de Ridder, N., and van Keulen, H. 2006. Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems* 88(1): 8–27.

Gyasi, E.A., Fosu, M., Kranjac-Berisavljevic, G., Mensah, A.M., Obeng, F., Yiran, G.A.B., and Fuseini, I. 2014. *Building urban resilience: Assessing urban and peri-urban agriculture in Tamale, Ghana*. Nairobi: United Nations Environment Programme (UNEP).

Jahnke, H.E. 1982. *Livestock production systems and livestock development in tropical Africa*. Kiel: Kieler Wissenschaftsverlag Vauk.

Jaleta, M., Kassie, M., and Shiferaw, B. 2013. Tradeoffs in crop residue utilization in mixed crop–livestock systems and implications for conservation agriculture. *Agricultural Systems* 121: 96–105.

Janik, L.J., Skjemstad, J.O., and Merry, R.H. 1998. Can mid infrared diffuse reflectance analysis replace soil extractions? *Australian Journal of Experimental Agriculture* 38(7): 681–696.

Jimenez, R.R., and Ladha, J.K. 1993. Automated elemental analysis: A rapid and reliable but expensive measurement of total carbon and nitrogen in plant and soil samples. *Communications in Soil Science and Plant Analysis* 24(15-16): 1897–1924.

Kihara, J., Bationo, A., Mugendi, D.N., Martius, C., and Vlek, P.L.G. 2011. Conservation tillage, local organic resources and nitrogen fertilizer combinations affect maize productivity, soil structure and nutrient balances in semi-arid Kenya. *Nutrient Cycling in Agroecosystems* 90 (2): 213–225.

Kisinyo, P.O., Othieno, C.O., Gudu, S.O., Okalebo, J.R., Opala, P.A., Ng'etich, W.K., Nyambati, R.O., Ouma, E.O., Agalo, J.J., Kebeney, S.J., Too, E.J., Kisinyo, J.A., and Opile, W.R. 2014. Immediate and residual effects of lime and phosphorus fertilizer on soil acidity and maize production in western Kenya. *Experimental Agriculture* 50(01): 128–143.

Kolawole, O.D. 2013. Soils, science and the politics of knowledge: How African smallholder farmers are framed and situated in the global debates on integrated soil fertility management. *Land Use Policy* 30(1): 470–484.

Long, J.S., and Freese, J. 2001. Regression models for categorical dependent variables using Stata. College Station, Texas: Stata Press.

Mairura, F.S., Mugendi, D.N., Mwanje, J.I., Ramisch, J.J., Mbugua, P.K., and Chianu, J.N. 2007. Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. *Geoderma* 139(1-2): 134–143.

Marenya, P.P., and Barrett, C.B. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy* 32(4): 515–536.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merckx, R., Chianu, J., and Vanlauwe, B. 2009. Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. *Experimental Agriculture* 45(01): 61-75.

Noltze, M., Schwarze, S., and Qaim, M. 2012. Understanding the adoption of system technologies in smallholder agriculture: The system of rice intensification (SRI) in Timor Leste. *Agricultural Systems* 108: 64–73.

Odendo, M., Obare, G., and Salasya, B. 2010. Farmers' perceptions and knowledge of soil fertility degradation in two contrasting sites in western Kenya. *Land Degradation and Development* 21(6): 557–564.

Odendo, M., Obare, G., and Salasya, B. 2009. Factors responsible for differences in uptake of integrated soil fertility management practices amongst smallholders in western Kenya. *African Journal of Agricultural Research* 4(11): 1303–1311.

Odendo, M., Ojiem, J., Bationo, A., and Mudeheri, M. 2007. On-farm evaluation and scaling-up of soil fertility management technologies in western Kenya. *Nutrient Cycling in Agroecosystems* 76(2-3): 369–381.

Ogunlana, E.A. 2004. The technology adoption behavior of women farmers: The case of alley farming in Nigeria. *Renewable Agriculture and Food Systems* 19(01): 57–65.

Okalebo, J.R., Gathua, K.W., and Woomer, P.L. 1993. *Laboratory methods of soil and plant analysis: A working manual.* Nairobi: Tropical Soil Biology and Fertility Programme.

Pretty, J., Toulmin, C., and Williams, S. 2011. Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability* 9(1): 5–24.

Sanginga, N., and Woomer, P.L. 2009. *Integrated soil fertility management in Africa: Principles, practices and developmental process.* Nairobi: TSBF-CIAT.

Schlecht, E., Buerkert, A., Tielkes, E., and Bationo, A. 2007. A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems* 76(2-3): 109–136.

Schlecht, E., and Buerkert, A. 2004. Organic inputs and farmers' management strategies in millet fields of western Niger. *Geoderma* 121(3-4): 271–289.

Shepherd, K.D., and Walsh, M.G. 2002. Development of reflectance spectral libraries for characterization of soil properties. *Soil Science Society of America Journal* 66(3): 988-998.

Taruvinga, A., Visser, M., and Zhou, L. 2016. Determinants of rural farmers' adoption of climate change adaptation strategies: Evidence from the Amathole District Municipality, Eastern Cape Province, South Africa. *International Journal of Environmental Science and Development* 7(9): 687–692.

Teklewold, H., Kassie, M., and Shiferaw, B. 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics* 64(3): 597–623.

Terhoeven-Urselmans, T., Vagen, T.-G., Spaargaren, O., and Shepherd, K.D. 2010. Prediction of soil fertility properties from a globally distributed soil mid-infrared spectral library. *Soil Science Society of America Journal* 74(5): 1792-1799.

Tittonell, P., Misiko, M. and Ekise, I. 2008a. Talking soil science with farmers. *Leisa-Leusden* 2 (2): 15–17.

Tittonell, P., Shepherd, K., Vanlauwe, B., and Giller, K. 2008b. Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya: An application of classification and regression tree analysis. *Agriculture, Ecosystems and Environment* 123(1-3): 137–150.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., and Giller, K.E. 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya. *Agriculture, Ecosystems and Environment* 110(3-4): 149–165.

Vanlauwe, B., Descheemaeker, K., Giller, K.E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., and Zingore, S. 2015. Integrated soil fertility management in Sub-Saharan Africa: Unravelling local adaptation. *Soil* 1(1): 491–508.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., and van Asten, P. 2014. Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8: 15–22.

Vanlauwe, B., and Zingore, S. 2011. Integrated soil fertility management: An operational definition and consequences for implementation and dissemination. *Better Crops* 95(3): 4–7.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L., and Sanginga, N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture* 39(1): 17–24.

Vanlauwe, B., Tittonell, P., and Mukalama, J. 2007. Within-farm soil fertility gradients affect response of maize to fertiliser application in western Kenya. *Nutrient Cycling in Agroecosystems* 76(2-3): 171–182.

Viscarra Rossel, R.A., Walvoort, D., McBratney, A.B., Janik, L.J., and Skjemstad, J.O. 2006. Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. *Geoderma* 131(1-2): 59–75.

Williams, R. 2006. Generalized ordered logit/partial proportional odds models for ordinal dependent variables. *The Stata Journal* 6(1): 58–82.

Wolfe, R., and Gould, W. 1998. sg76: An approximate likelihood-ratio test for ordinal response models. *Stata Technical Bulletin* 42: 24–27.

Wollni, M., Lee, D.R., and Thies, J.E. 2010. Conservation agriculture, organic marketing, and collective action in the Honduran hillsides. *Agricultural Economics* 41(3-4): 373–384.

4 Impacts of integrated soil fertility management on yield and household income: The case of Tamale (Ghana) and Kakamega (Kenya)

Ivan S. Adolwa[1], Stefan Schwarze[2*], Andreas Buerkert[1]

[1]Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, Steinstr. 19, Universität Kassel, D-37213 Witzenhausen, Germany

[2]Department of Agricultural Economics and Rural Development, Georg-August-Universität Göttingen, Platz der Göttinger Sieben 5, D-37073 Göttingen, Germany

*Corresponding author: s.schwarze@agr.uni-goettingen.de

4.1 Abstract

Integrated soil fertility management (ISFM) has been promoted by research and philanthropic organizations as well as governments in an attempt to increase crop yields and improve livelihoods of smallholder farmers in Africa. As this has largely been a continent-wide initiative, it is surprising that there is still scant information on its impact on crop yields and household income. This paper uses a counterfactual model to assess ISFM impact on yields and total household incomes using farm household data from Tamale (northern Ghana) and Kakamega (western Kenya). Descriptive results show that maize yields on plots where ISFM was implemented are higher but there are no differences in profitability. In addition, total household income is higher for adopters than non-adopters in Tamale. The analyses reveal that ISFM adoption leads to an increase in maize yields by up to 16% both in Tamale and Kakamega. Adoption of the innovation increases total household income by 20% in Tamale. Some implications for future research are discussed.

Keywords: Counterfactual models; Integrated Soil Fertility Management; Maize yield; Total household income; Technology impact

4.2 Introduction

Sustained agricultural productivity in Africa has been hampered by rapid population growth coupled with declining soil fertility levels. This low productivity poses a major threat to food security, particularly in Sub-Saharan Africa (SSA), where the population has increased five-fold from pre-independence levels (Kristjanson et al. 2012; Jayne et al. 2014; United Nations 2015). The food crop of intense interest with regard to food security in Africa is the maize crop. It is the most important food crop in the continent encompassing more than 40% of cereal production (Byerlee and Heisey 1996; Maredia et al. 2000; Nuss and Tanumihardjo 2011). Maize constitutes a major part of the cuisine of local people and is used to make a variety of dishes served at various times of the day (Nuss and Tanumihardjo 2011; Groote and Kimenju 2012). However, maize is a highly nutrient-demanding crop and its demand for nitrogen nutrients, in particular, is almost rapacious (Lotter 2015). Declining soil fertility and the need to feed a bulging population has thus led to calls for sustainable intensification to boost crop and livestock production. Integrated Soil Fertility Management (ISFM) is a system innovation that could be crucial in sustainable agricultural intensification. ISFM has been at the core of initiatives by governments and international donors to improve agricultural production in Africa. The Alliance for a Green Revolution in Africa (AGRA) was behind such an initiative, which unfolded between 2008 and 2012 in northern Ghana, western Kenya and other regions of the continent (Bellwood-Howard 2014). Contextually, ISFM is understood as a suite of soil fertility management practices that include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions to maximize agronomic use efficiency of the applied nutrients and improve crop productivity (Vanlauwe et al. 2010). Along with food security, improving the economic welfare of often marginalized rural communities has been a top priority for policy makers as well as research and development agents. It is envisioned that farming households could escape poverty traps by adopting agricultural technologies, which are in turn expected to boost productivity to the extent of producing a marketable surplus (Barrett 2008; Cunguara and Darnhofer 2011). Nonetheless, the first barrier to be overcome is that of adoption. System innovation (e.g. ISFM, conservation agriculture, agroforestry) adoption has been a subject of intense discussion in the recent years as its scale-out, as well as scale-up in Sub-Saharan Africa (SSA) has remained limited (Vanlauwe et al. 2014; Lambrecht et al. 2015). While a lot of emphasis has been placed on assessing socio-economic and contextual drivers of agricultural technology adoption, there has been less focus on their viability regarding yield and income impacts. Accordingly, it has become imperative to assess the viability of promoted technologies in improving the welfare of affected communities in terms of household income and food security status (Cunguara and Darnhofer 2011).

There are plenty of empirical studies that have assessed the impact of green revolution or single technologies such as improved maize seed and chemical fertilizers at micro or household level (Mendola 2007; Kijima et al. 2008; Becerril and Abdulai 2010; Cunguara and Darnhofer 2011; Kassie et al. 2011; Kabunga et al. 2014; Mathenge et al. 2014; Khonje et al. 2015). Fewer studies, though, have evaluated the impact of system innovation or natural resource management (NRM) technologies on crop yield and/or household income also at the micro-level (Bolwig et al. 2009; Noltze et al. 2013; Teklewold et al. 2013; Abdulai and Huffman 2014). An underlying feature of these studies is the attempt to estimate causal effects of technology adoption, which means accounting for the problem of selection bias and the associated endogeneity. The selection problem occurs as farmers often take into account outcomes such as potential net benefits when making adoption decisions hence they self-select into programs making it virtually impossible to assign them randomly into adopter and non-adopter categories (Kassie et al. 2011). To solve this problem analysts have employed strategies through which it is possible to impose suitable counterfactuals on cross-sectional data. As a result, regression or propensity score matching (PSM) methods or a combination of the two have been widely deployed (Becerril and Abdulai 2010; Cunguara and Darnhofer 2011; Kassie et al. 2011). PSM methods are more popular as they ensure comparison of an outcome variable is carried out between households with similar characteristics (Cunguara and Darnhofer 2011). Others have extended these methods by including endogeneous switching techniques in their analyses, which serve the same purpose of accounting for self-selection, but also account for heterogeneous impacts of farm and household covariates on outcome variables such as yield or income (Noltze et al. 2013; Khonje et al. 2015). In rarer cases, simulation models (e.g. OLYMPE model) have been used to simulate medium to long-term economic impacts of agricultural technologies (Corbeels et al. 2014). To our knowledge, no study yet has empirically evaluated impacts of ISFM adoption using any of the measures above. Relevant studies have simply used mean differences to evaluate yields and economic gains of ISFM implementation (Nezomba et al. 2015; Gnahoua et al. 2016).

This study aims to address this gap in the existing literature by providing a micro perspective of ISFM impacts on maize yield and total household income using regression analysis within a counterfactual model. Given the anticipated benefits, a relevant question is whether ISFM has achieved its promise of improving farmers' welfare through increased productivity and income. We hypothesize that application of ISFM components has a positive effect on maize yield and total household income.

4.3 The ISFM innovation

In principle, ISFM is the application soil fertility management practices that include appropriate fertilizer and organic input management in combination with the use of improved germplasm (Sanginga and Woomer 2009). The knowledge to adapt these practices to local conditions is essential to maximize nutrient use efficiency and crop productivity. For instance, correcting soil acidity or effectively targeting scarce organic inputs is essential to enhance the agronomic efficiency (AE). A favorable AE results from the interaction between capture efficiency, that is, the proportion of nutrients taken up and the conversion efficiency, that is, the yield realized per amount of nutrients taken up (Giller et al. 2006; Vanlauwe et al. 2010). Therefore, ISFM consists of several intermediary phases or steps that lead to complete ISFM. Farmers employing conventional practices use traditional seed varieties and apply little or no fertilizer. Even where fertilizers are used, the management of its application is sub-optimal (Vanlauwe et al. 2010). The first step involves the use of fertilizer combined with improved germplasm. In the ISFM paradigm, fertilizer use is considered an appropriate entry point as this leads to higher production of biomass, which can subsequently be recycled as organic inputs (Sanginga and Woomer 2009). It follows then that the second step entails the addition of organic amendments. The final or complete phase is when the prior steps in conjunction with local adaptation are adopted. Vanlauwe et al. (2010) reiterate that all the different steps are part of ISFM, but maximal AE or 'complete ISFM' is only attained when all steps are taken. Thus a farmer who uses fertilizer and improved germplasm is implementing one component of ISFM. However, a complete ISFM practitioner, in addition, uses and recycles locally available organic inputs, takes corrective measures to alleviate constraints such as acidity or soil erosion, and/or targets application of scarce organic resources (Sanginga and Woomer 2009; Vanlauwe et al. 2010; Vanlauwe et al. 2015). Appropriate fertilizer management, for instance, point placement of fertilizer and use of the right fertilizer rates are also vital for the successful implementation of ISFM (Bationo et al.

2008). Other additional practices embedded within the ISFM framework include cereal-legume intercrops and rotations, fertilizer micro-dosing and water harvesting techniques such as 'zai' or tied-ridges.

4.4 Materials and methods

4.4.1 The empirical framework

Impact studies often are faced with an impact evaluation problem, which is whether the well-being of adopters, as opposed to non-adopters, is actually as a result of technology uptake or due to other factors related to technology adoption (Mendola 2007). It is necessary to have information on the counterfactual outcome to adjudge causal effects, which can only be obtained from experimental data (Mendola 2007; Vittinghoff et al. 2011). In observational studies, the problem of self-selection bias frequently arises. It occurs when unobserved factors influence the decision to adopt as well as the outcome variable of interest (Diagne and Demont 2007; Noltze et al. 2013; Abdulai and Huffman 2014). To address this we use regression analysis within a potential-outcome model also known as the Rubin casual model or counterfactual model following Woolridge (2002) and Wooldridge (2010).

We want to measure the effect of treatment (that is, ISFM adoption). Hence our interest is the difference in the outcomes with and without treatment, $y_1 - y_0$. The object of our interest is the average treatment effect on the treated (ATET), which is the effect of the treatment on farmers who use the ISFM innovation. Other parameters estimated include: the average treatment effect (ATE), which is the effect of the treatment on a randomly chosen farmer from the population and the potential-outcome mean (POM), that is, the average potential outcome for a given treatment level.

ATET, ATE and POM are denoted as:

$$ATET \equiv \mathrm{E}(y_1 - y_0 | w = 1) \quad (1)$$

$$ATE \equiv \mathrm{E}(y_1 - y_0)$$

$$POM_w \equiv \mathrm{E}(y_w)$$

As we observe either y_0 or y_1 for each farmer, but not both, the observed outcome is:

$$y = (1 - w) + wy_1 = y_0 + w(y_1 - y_0), \qquad (2)$$

Where w is the treatment indicator or status (ISFM adoption or non-adoption).

Assuming independence between treatment status and potential outcome ATET and ATE are equal and estimating ATET using equation (2), we have:

$$ATET = ATE = \mathrm{E}(y|w = 1) - \mathrm{E}(y|w = 0) \qquad (3)$$

The right side of the equation is estimated by the difference in the sample average of y for treated units and the sample average of y for untreated units. A randomized treatment ensures that the estimates of the difference in means are unbiased and consistent, but as alluded earlier this randomization is infeasible in a post-hoc study due to self-selection into treatment.

Assuming no confounding influences, that is, the treatment depends only on 'observables' and not on the 'unobservables', then it is possible to estimate average treatment effects using the 'ignorability of treatment' assumption, initially espoused by Rosenbaum and Rubin (1983). The core of this assumption is the conditional mean independence (CI assumption) that constrains the dependence between the treatment model and potential outcomes. The CI assumption can be represented as follows:

Assumption ATE.1′: (a)$\mathrm{E}(y_0|\mathrm{x}, w) = E(y_0|\mathrm{x})$; and (b)$\mathrm{E}(y_1|\mathrm{x}, w) = E(y_1|\mathrm{x})$, (4)

Where x denote a vector of observed covariates. The average treatment effect conditional on x can be written as:

$$ATE(\mathrm{x}) = \mathrm{E}(y_1 - y_0|\mathrm{x}) = r(\mathrm{x}) \qquad (5)$$

Thus ATE is the expected value of $r(\mathrm{x})$ across the entire population, written mathematically as:

$$ATE = \mathrm{E}[r(\mathrm{x})] \qquad (6)$$

The next step is to estimate $r(\cdot)$, after which ATE can be estimated by averaging across the entire random sample of the population. Various procedures can be used to estimate $r(\cdot)$ and they include the standard regression methods, propensity score matching (PSM) procedures, nearest-neighbor matching procedures and instrumental variable methods (Woolridge 2002; Brand and Halaby 2006; Mendola 2007). Indeed, PSM procedures have been applied widely in studies estimating impacts of agricultural technologies on income or productivity (Mendola 2007; Cunguara and Darnhofer 2011; Kassie et al. 2011). However, Brand and Halaby (2006) argue that the PSM and regression methods such as regression adjustment yield rather similar patterns of results. Here, we focus on regression methods.

Regression methods to estimate causal effects

Following Woolridge (2002), we estimate ATE and ATET using equation (2) together with assumption ATE.1′ and estimators of $ATE(\mathrm{x})$. Therefore, we have:

$$\mathrm{E}(y|\mathrm{x}, w = 1) - \mathrm{E}(y|\mathrm{x}, w = 0) = \mathrm{E}(y_1|\mathrm{x}) - E(y_0|\mathrm{x}) = ATE(\mathrm{x}) \quad (7)$$

As we have a random sample on y, w, x from the population of interest, $r_1(\mathrm{x}) \equiv \mathrm{E}(y|\mathrm{x}, w = 1)$ and $r_0(\mathrm{x}) \equiv \mathrm{E}(y|\mathrm{x}, w = 0)$ are identified non-parametrically given the conditional expectation depending entirely on observables. So, we assume $r_1(\mathrm{x})$ and $r_0(\mathrm{x})$ are known, which means $ATE(\mathrm{x})$ can be identified. Thus a consistent estimator of ATE using the CI assumption (considered to be fairly weak) is:

$$A\hat{T}E = N^{-1} \sum_{i=1}^{N} [\hat{r}_1(\mathrm{x}_i) - \hat{r}_0(\mathrm{x}_i)], \quad (8)$$

While that of ATET is:

$$A\hat{T}ET = (\sum_{i=1}^{N} w_i)^{-1} \{\sum_{i=1}^{N} W_i [\hat{r}_1(\mathrm{x}_i) - \hat{r}_0(\mathrm{x}_i)]\} \quad (9)$$

Where N is the size of the random sample, and $\hat{r}_1(\mathrm{x})$ and $\hat{r}_0(\mathrm{x})$ are taken to be consistent estimators. To estimate ATE using standard parametric regression methods, counterfactual outcomes are decomposed into their means (with a stochastic part of zero mean) as follows:

$$y_0 = \mu_0 + \upsilon_0, \qquad E(\upsilon_0) = 0 \tag{10}$$
$$y_1 = \mu_1 + \upsilon_1, \qquad E(\upsilon_1) = 0$$

This is inserted into equation (2) to give:

$$y = \mu_0 + (\mu_1 + \upsilon_1)w + \upsilon_0 + w(\upsilon_1 - \upsilon_0) \tag{11}$$

An important assumption is that $\upsilon_1 - \upsilon_0$ has zero mean conditional on x, hence obtains a standard regression model under CI assumption or ATE.1′. This leads to the following regression equation:

$$E(y|w, \mathrm{x}) = \mu_0 + \alpha w + g_0(\mathrm{x}) + w[g_1(\mathrm{x}) - g_0(\mathrm{x})], \tag{12}$$

Where α = *ATE*, $g_0(x) \equiv E(\upsilon_0|\mathrm{x})$, and $g_1(x) \equiv E(\upsilon_1|\mathrm{x})$

To exploit linearity, $g_0(\cdot)$ and $g_1(\cdot)$ are replaced with parametric functions of x; $\eta_0 + h_0(x)\beta_0$ and $\eta_1 + h_1(x)\beta_1$, which we both assume are linear to x for notational simplicity. Thus equation (12) is re-written as:

$$\mathrm{E}(y|w, \mathrm{x}) = \gamma + \alpha w + \mathrm{x}\beta_0 + w \cdot (\mathrm{x} - \psi)\delta, \tag{13}$$

Where β_0 and δ are vectors of unknown parameters and $\psi \equiv \mathrm{E(x)}$. ATE is assured as the coefficient on *w* and is estimated as α in the above equation when the mean is subtracted from x as depicted below:

$$y_i \text{ on } 1, w_i \mathrm{x}_i w_i(\mathrm{x_i} - \bar{\mathrm{x}}), \qquad i = 1,2, \ldots, N \tag{14}$$

A consistent estimator for ATET is written as:

$$A\hat{T}ET = \hat{\alpha} + (\textstyle\sum_{i=1}^{N} w_i)^{-1}\left[\sum_{i=1}^{N} w_i(\mathbf{x}_i - \bar{\mathbf{x}})\hat{\delta}\right] \tag{15}$$

In the above case, ATET averages x over the sub-sample w_i = 1.

Endogenous treatment effects estimation

We add the aspect of endogeneity to the framework which takes into account the unobservable factors that may affect the potential outcome. For instance, farmers who adopt may be influenced by the adopting decisions of other farmers in their vicinity. The instrumental variable approach is one method for controlling for unobservables (Shiferaw et al. 2014). In such cases, a strong instrument which is strongly correlated with the treatment variable but not the outcome variable is required.

The ATET is estimated using the generalized methods of moments, which for a linear model can be written as (cf. Stata 14 manual[6]):

$$\frac{1}{n}\sum_{i=1}^{n}\left\{\left(\mathrm{x}_i'\hat{\beta}_{11}+\hat{\upsilon}_i\hat{\beta}_{21}\right)\frac{n}{n_t}-\widehat{POM}0\,\frac{n}{n_t}-\widehat{ATET}\right\}=0, \qquad (16)$$

Where n is the number of observations, n_t is the number of treated units, and $\hat{\beta}_{11}$, $\hat{\beta}_{21}$, $\widehat{POM}0$, and $\widehat{ATET}$ are parameters of the model. We fit a probit estimator to obtain $\hat{\upsilon}_i$, which is the difference between the treatment and the estimate of $E(t_i|\mathrm{z}_i)$, t_i being the observed binary treatment and z_i a set of regressors.

4.4.2 Study areas

This study was conducted in Tamale (9° 24′ N, 0° 51′ W), Ghana and Kakamega (0˚ 02' N, 34˚ 34' E), Kenya. Tamale in the northern Ghana region has an average annual rainfall of 1100mm and is situated at an altitude of 183 m above sea level (asl). The population of Tamale is 0.48 Mio and the population density is 480 persons km^{-2}. The soils are dominated by savannah Ochrosols (derived from sandstone parent material), which are generally poor in soil nutrients (Braimoh and Vlek 2006; Yiridoe et al. 2006). Kakamega is located in the Lake Victoria region of western Kenya, has an annual rainfall 1600-2000 mm, a total population of 1.6 Mio, a population density of 550 persons km^{-2} and average altitude of 1535 m asl. The soils are classified as mostly as ferralo-orthic Acrisols (well drained, deep sandy clay/clay soils), ferralo-orthic/chromic Acrisols (well drained, very deep sandy clay/clay soils) and humic Acrisols (well drained, sandy clay/clay soils) with acidic humic topsoil (Jaeztold et al. 2005). Maize (*Zea mays*

[6] http://www.stata.com/manuals14/teeteffects.pdf

L.) is the staple crop at both study locations and constitutes a large share of the dietary intake of the local people. The most common vegetables in Tamale include jute mallow (*Corchorus olitorius*), roselle (*Hibiscus sabdariffa L.)*, amaranth (*Amaranthus cruentus*) pepper (*Capsicum* sp.) and okra (*Abelmoschus esculentus*) which are indigenous. Lettuce (*Lactuca sativa*) and cabbage (Brasssica oleracea) are commonly grown within city confines due to existing market incentives. In the more urban sections of Kakamega, vegetables such as cabbage and kales (*Brassica oleracea*) are grown. Traditional vegetables grown here include spider plant (*Gynandropsis gynandra*), sunnhemp (*Crotalaria brevidens*) African black nightshade (*Solanum nigrum*), amaranth, jute mallow, and cowpea leaves (*Vigna unguiculata*). Rice (*Oryza sativa* or *Oryza glaberrima*) is grown as both a food and cash crop in Tamale. Other crops including yam (*Dioscorea rotundata*) and groundnut (*Arachis hypogaea*) are cultivated by most farmers here for both consumption and income generation. In Kakamega, sugarcane (*Saccharum officinarum*) is the major cash crop while tea (*Camellia sinensis*) is also cultivated but only in the wetter zones. Farmers often cultivate beans (*Phaseolus vulgaris*), bananas (*Musa* sp.), sweet potatoes (*Ipomoea batatas*) and other crops to supplement their diets.

The rationalization behind the selection of the study sites is based on the AGRA-commissioned study in 2008 as well as the Urban Food^{Plus} (UFP) project based in West Africa. AGRA identified and selected 24 projects on ISFM targeting the major breadbasket areas of the 13 AGRA countries of which Kenya and Ghana are included. Criteria used for their selection included different challenges on ISFM, ease for up-scaling and representation of breadbasket regions of SSA. We filtered down to two representative yet contrasting regions selected to represent the eastern and western African region.

4.4.3 Field surveys and data

Data were collected through a household survey between July 2014 and February 2015. To select respondents, a stratified random sampling approach was utilized both in Tamale and Kakamega. Farming households were stratified into participants in ISFM activities and non-participants. Lists of participating farmers were compiled with the assistance of extension officers, local research institutions, village elders and lead farmers that had been involved in disseminating ISFM activities. Non-participants were randomly selected from a list of farmers, which was obtained from the UFP project in Tamale (Bellwood-Howard et al. 2015) and from the Agricultural Sector Development Support Programme of Kenya in Kakamega (Agricultural Sector Development Support Programme 2014). As a result, 285 farmers were selected in Tamale and 300 in Kakamega. However, some were dropped due to missing information thus data from 282 and 290 farmers in Tamale and Kakamega, respectively, was utilized. The main survey instrument was a structured questionnaire containing sections on socio-demographic characteristics of household members, farm characteristics, crop production and management, as well as off-farm activities. The reference period for all economic activities was twelve months prior to the interview. In addition, soil sample data were drawn from 322 plots in Tamale and 459 in Kakamega at 0-20 cm depth. One plot in Tamale was dropped in the subsequent analysis thus 321 plots were considered in the analysis.

Using survey data, we conducted an economic analysis to assess the impact of adopting ISFM practices on yield as well as net income at both study locations. Cost and returns of maize production was calculated at plot level to estimate differences between conventional and ISFM practices. ISFM entailed component 1 (fertilizer and improved seed), component 2 (fertilizer, improved maize seed and organic amendments such as manure or compost) and component 3 (the full package entailing the aforementioned practices plus a local adaptation strategy such as liming, terracing or crop residue use). Cost items such as labor, input (fertilizer, seed, herbicide or pesticide) and variable (e.g. rent of land, tractor hire, sacks, transport and others) expenses were included in the analysis. We also determined annual total household income, which encompassed revenues from sales of livestock, crops including maize, vegetables and other crops as well as off-farm income, less any incurred costs. This approach has been applied in past studies that assessed impacts of agricultural technologies on household income (Cunguara and Darnhofer 2011). To determine causal effects on adoption, farmers were disaggregated into either conventional (non-adopters) or adopters (ISFM), that is, those who used either component one, two or three of ISFM. Statistical analysis was done using Stata (version 13 and 14) for the modeling as well as t-tests for the descriptive economic analysis.

4.5 Results and discussion

4.5.1 Descriptive statistics

Land tenure plays a crucial role in Tamale with 33% of adopters of the ISFM innovation holding a title to at least one of their plots compared to only 11% for non-adopters (Table 15). The rapid expansion of the city has resulted in a situation where many farmers are faced with the problem of land scarcity. Conversely in Kakamega, a higher share of non-adopters than adopters have land titles to one or more plots they cultivate. Residence within the urban or peri-urban areas seems to be important for ISFM adopters at both study locations, although Kakamega has much fewer households residing within city confines (Table 1). Proximity to urban centers may proffer farmers with easy access to input and output markets (Kuusana and Eledi 2015). Thus it is likely adopters of agricultural innovations would reside close to cities. Variables related to farm size such as land and maize area cultivated are not statistically different between the two categories.

At the household level, individual characteristics such as education and off-farm occupation vary between the two sets of farmers regardless of the site (Table 15). ISFM adopters have more years of schooling and are more likely to have off-farm employment. Households of non-adopters in the Tamale sample are larger than those of adopters. This is expected as most of them reside in rural areas where households tend to be larger than in towns. Access to credit is higher for ISFM practitioners than for the conventional farmers in Tamale. To measure information constraint, we used a procedure employed by Matuschke and Qaim (2009) whereby farmers who acquired information on ISFM innovations via formal sources were considered not to be information constrained. Non-ISFM farmers in Kakamega are more constrained in terms of information access than their adopting counterparts. At the plot level, fields of non-ISFM farmers in Tamale have higher total carbon than those of their adopting counterparts. Schlecht and Buerkert (2004) posit that farmers may opt to refrain from applying inputs on the more perceived silty/clayey fertile patches of land or plots as opposed to the sandy ones. Although pH was not statistically different between adopters and non-adopters for both sites, the fields in Kakamega were more fertile as they had higher soil carbon, but were more acidic than those in Tamale. Farmer management, as well as associated edaphic factors may play an important role in the differing characteristics in soil properties between the two agro-ecological zones. All the variables in Table 15 are subsequently utilized in the regression analysis.

Table 15 Descriptive statistics for Tamale (Ghana) and Kakamega (Kenya)

	Tamale				Kakamega			
	Means (SD)				Means (SD)			
	All	ISFM	Conventional		All	ISFM	Conventional	
Household level characteristics	N=282	N=40	N=242		N=290	N=244	N=46	
Farm and location variables								
Total land area cultivated (acres)	7.52 (9.13)	8.60 (9.94)	7.34 (9.00)		2.17 (2.43)	2.24 (2.41)	1.77 (2.50)	
Total maize area cultivated (acres)	3.65 (3.50)	4.57 (5.76)	3.50 (2.95)		1.21 (1.30)	1.25 (1.31)	0.99 (1.22)	
Tropical livestock units[a]	3.97 (7.99)	6.82 (16.12)	3.50 (5.55)		2.03 (1.89)	2.03 (1.82)	2.06 (2.24)	
Land title[b] (%)	14.18 (34.95)	32.50 (47.43)	11.16 (31.55)	***	66.90 (47.14)	64.75 (47.87)	78.26 (41.70)	*
Household in urban/peri-urban area (%)	32.62 (46.97)	62.50 (49.03)	27.69 (44.84)	***	20.34 (40.32)	22.54 (41.87)	8.70 (28.49)	***
Household variables								
Age of HH head (years)	52.15 (13.84)	51.10 (15.54)	52.32 (13.57)		52.66 (13.07)	52.66 (13.08)	52.70 (13.16)	
HH head education level (years)	2.33 (4.95)	5.68 (6.26)	1.78 (4.48)	***	8.97 (3.98)	9.16 (3.88)	7.91 (4.36)	*
HH size (count)	12.95 (7.18)	11.23 (6.86)	13.23 (7.20)	*	7.33 (3.58)	7.47 (3.65)	6.61 (3.12)	
HHs with off-farm occupation (%)	74.82 (54.39)	90.00(30.38)	72.31 (57.05)	***	58.97 (49.27)	62.330 (48.56)	41.30 (49.78)	**
Financial and social capital variables								
Access to formal credit (%)	17.73 (38.26)	30.00 (46.41)	15.70 (36.46)	*	87.93 (32.63)	88.93 (31.44)	82.61 (38.32)	
Member of farmer group (%)	66.31 (47.35)	57.50 (50.06)	67.77 (46.83)		70.00 (45.90)	71.31 (45.32)	63.04 (48.80)	
Information constraint (%)	20.21(40.23)	20.00 (40.51)	20.25(40.27)		13.79 (34.54)	11.48 (31.94)	26.09 (44.40)	**
Plot level characteristics	N=321	N=36	N=285		N=459	N=369	N=90	
Plot within or near homestead (%)	40.81(49.22)	41.67 (50.00)	40.70 (49.21)		82.00 (38.30)	81.00 (39.00)	87.00 (34.00)	
pH	6.19 (0.83)	6.21(0.65)	6.19 (0.85)		4.82 (0.38)	4.81 (0.39)	4.89 (0.32)	
Total carbon (%)	0.74 (0.59)	0.65 (0.29)	0.76 (0.62)	*	1.54 (0.45)	1.54 (0.45)	1.57 (0.50)	

[a]Tropical livestock units computed following Jahnke (1982) and Odendo et al. (2009)
[b]Land title defined as having a title for at least one of the plots under cultivation.
HH stands for household
* Mean values for ISFM and Non-ISFM farmers are significantly different at 10%.
** Mean values for ISFM and Non-ISFM farmers are significantly different at 5%.
*** Mean values for ISFM and Non-ISFM farmers are significantly different at 1%.

Table 16 Costs and returns on ISFM and conventional maize plots in Tamale (Ghana) and Kakamega (Kenya)

	Tamale				Kakamega			
		Means (SD)			Means (SD)			
	All	ISFM	Conv.		All	ISFM	Conv.	
Yield (t/ha)	1.62	2.06	1.56	*	1.78	1.91	1.21	***
	(1.22)	(1.54)	(1.16)		(1.92)	(2.07)	(0.95)	
Market price (US$/t)	142.23				309.55			
Gross revenue (US$/ha)	230.51	294.09	222.48	*	549.71	592.61	373.82	***
	(173.01)	(218.55)	(218.02)		(595.83)	(641.38)	(295.14)	
Hybrid seed quantity	2.00	13.51	0.55	***	22.49	23.18	19.68	
(kg/ha)	(0.51)	(22.66)	(3.34)		(36.05)	(26.81)	(60.87)	
Seed costs (US$/ha)	1.00	5.80	0.40	***	63.86	72.95	26.62	
	(3.46)	(6.85)	(2.10)		(526.70)	(585.91)	(79.92)	
Fertilizer quantity (kg/ha)	182.56	217.05	178.20		180.03	193.43	125.09	
	(185.52)	(167.52)	(187.44)		(361.92)	(227.61)	(675.31)	
Fertilizer costs (US$/ha)	60.46	88.23	56.95		114.03	133.05	36.08	***
	(176.48)	(203.59)	(172.84)		(190.37)	(203.81)	(84.32)	
Pesticide and herbicide	7.77	9.64	7.54		1.02	1.26	0.03	***
costs (US$/ha)	(10.27)	(9.04)	(10.40)		(5.44)	(6.04)	(0.25)	
Hired labor costs	8.51	17.47	7.38	*	125.95	132.02	101.09	
(US$/ha)	(29.58)	(32.96)	(28.99)		(201.61)	(206.69)	(178.22)	
Other variable costs	23.82	21.56	24.10		67.52	73.28	43.90	***
(US$/ha)	(15.84)	(12.49)	(16.21)		(127.64)	(137.59)	(69.76)	
Net maize income	128.95	151.39	126.12		177.32	180.05	166.11	
(US$/ha)	(225.11)	(193.44)	(228.94)		(786.93)	(864.29)	(312.87)	

*Statistically significant at the 10% level.
***Statistically significant at the 1% level.

Table 17 Annual household income (in US$) by activity in Tamale (Ghana) and Kakamega (Kenya)

	Tamale							Kakamega						
	All	(%)	ISFM	(%)	Conv.	(%)		All	(%)	ISFM	(%)	Conv.	(%)	
Maize	411.58	(39.71)	488.20	(24.05)	398.91	(45.74)		214.24	(13.76)	217.14	(13.45)	198.83	15.85)	
Other crops	130.32	(12.57)	66.65	(3.28)	140.84	(16.15)		110.89	(7.12)	131.33	(8.14)	2.49	(0.20)	***
Livestock	86.76	(8.37)	246.32	(12.13)	60.38	(6.92)		340.93	(21.90)	329.53	(20.42)	401.38	(31.99)	
Off-farm	407.80	(39.35)	1228.95	(60.54)	272.08	(31.19)	**	890.80	(57.22)	935.86	(57.99)	651.82	(51.96)	
Total household income	1036.46	(100)	2030.12	(100)	872.21	(100)	***	1556.86	(100)	1613.86	(100)	1254.52	(100)	
Per-capita income per day	0.46		1.07		0.36			1.09		1.11		1.02		

**Statistically significant at the 5% level.

***Statistically significant at the 1% level.

4.5.2 Maize yield and household income

An economic analysis was carried out to assess differences in yields and maize incomes between adopters and non-adopters of ISFM at the two study locations. Table 16 shows that there are maize yield differences between ISFM and conventional farmers at both sites.

Net maize income was not significantly different between components for both sites at prevailing market prices (Table 16). Although maize yield and gross revenue are relatively high in Kakamega, farmers spend more on hybrid seeds, fertilizer, and labor. Hence, this leads to a lower than expected net income accrued from the intensively cultivated ISFM plots. At the household level, we computed total household income derived from crop and livestock production including for home consumption, plus off-farm income. In our case, off-farm income constituted income from agricultural and non-agricultural wage labor, self-employment and remittances (Table 17). ISFM households in Tamale have five times more off-farm income and almost three-fold the total household income of conventional ones (Table 17). As for Kakamega, ISFM practitioners gain more income from crops such as sugarcane, groundnuts, and vegetables than non-ISFM farmers. Off-farm income constitutes a considerable share of total household income; 39% in Tamale and 57% in Kakamega (Table 17). For ISFM households this share is even higher. This is an indication of the crucial role of off-farm farm employment in farming households. While maize constituted the largest share of income in Tamale (40%), it contributed the least to the total household income in Kakamega (14%) among the income categories. Thus maize income is pivotal in Tamale, but this should not automatically be attributed to ISFM due to the possible overestimation or underestimation of its impacts. This calls for the use of counterfactual models to more accurately estimate yield and income effects of agricultural technologies.

4.5.3 Assessment of the effects of ISFM adoption on maize yields

To analyze yield effects, we estimate a yield model using ordinary least squares (OLS) at the plot level whose coefficients are used to calculate ATET of ISFM adoption. As the binary predictor variable, ISFM, is not endogenous we use a potential outcome model, which is deemed to give correct standard errors. Kijima et al. (2008) similarly used OLS having found no evidence for the existence of endogeneity. To test for endogeneity we use the share of adopters in a farmer's village as the instrument, which is highly correlated with the farmer's adoption behavior

(F(1,244)=30, *P*<0.001 for Tamale; F(1,298)=80, *P*<0.001 for Kakamega), but not with maize yields (*P*=0.162 for Tamale; *P*=0.207 for Kakamega). The latter result is also confirmed by the test of overidentifying restrictions (*P*=0.888 for Tamale; *P*=0.305 for Kakamega). We hence conclude that the share of adopters in a village is a valid instrument in this case.

The results of the effects of various covariates on maize yield are shown in Table 18. The model shows that ISFM adoption has an effect on maize yield both in Tamale ($p < 0.1$) and Kakamega ($p < 0.05$). However, when the improved seeds variable is controlled for in the Tamale model, adoption is not significant. This indicates that the effects of the innovation on maize yield are basically due to improved seeds. Conversely, additional components of ISFM contribute to this effect in Kakamega. Back in Tamale, the location of the maize plot is the plot level variable influencing maize yield ($p < 0.01$). Higher yields are obtained with increasing closeness to the homestead. This makes sense since farmers often find it economically convenient to apply inputs on fields closer to their homesteads as transportation costs are minimal. Farmers also consider crops grown in in-fields to be important in meeting household food requirements hence they are likely to invest more time and resources on this fields (Vanlauwe et al. 2015). The two study regions also have notable differences in land use patterns (Giller et al. 2011). On one hand, Kakamega farmers tend to have their fields clustered together in one location mostly close to their homesteads, and these fields are often titled. On the other hand, Tamale farmers will tend to cultivate fields that are far apart as the availability of farming land is dictated by the whims of local chiefs.

Contextual factors particularly those concerning interactions with institutional actors seem to play a pivotal role, at least in Tamale. Improved access to formal information sources increases maize yields as shown by the negative coefficient on information constraint ($p < 0.01$). Institutional actors are reported to have an important role in technology adoption and its impact on crop yields as they reduce uncertainty on the innovations (Abdullai and Huffman 2014). Here, the most likely formal sources of agricultural information would be NGOs or extension agents in the rural areas. In the urban and peri-urban zones, farmers have access to mass media (e.g. radio) and ICT (e.g. mobile phones) gadgets thus are likely to use these media to gain exposure to innovations. In the case of Kakamega, it is probable that the ISFM innovation has moved beyond the exposure stage somehow masking the influence of institutional contact, especially with regard to yield, which is subject to a host of widely varying factors.

Table 18 Determinants of maize yield on farmers' plots in Tamale, Ghana and Kakamega, Kenya

	Tamale		Kakamega
Variables	Model 1	Model 2	
ISFM adoption (1=yes)	0.141*	0.059	0.127**
	(0.082)	(0.083)	(0.064)
Plot located within homestead (1=yes)	0.168***	0.161***	-0.012
	(0.048)	(0.048)	(0.063)
pH	0.039	0.035	0.108
	(0.046)	(0.046)	(0.115)
Total C (%)	-0.030	-0.033	0.083
	(0.057)	(0.057)	(0.055)
HHs with off-farm occupation (1=yes)	0.032	0.037	-0.052
	(0.051)	(0.051)	(0.054)
Age of HH head (years)	0.001	0.002	-0.001
	(0.002)	(0.002)	(0.002)
Maize area cultivated (acres)	0.001	-0.001	-0.029
	(0.010)	(0.010)	(0.019)
Information constraint (1=yes)	-0.210***	-0.210***	0.012
	(0.062)	(0.062)	(0.072)
Fertilizer quantity (kg/ha) in log	0.508**	0.508**	0.684**
	(0.243)	(0.241)	(0.303)
Pesticide and herbicide costs (US$/ha)	0.163***	0.158***	-0.006
in log	(0.055)	(0.055)	(0.134)
Labor costs (US$/ha) in log	-0.204	-0.207	0.610***
	(0.231)	(0.232)	(0.203)
Hybrid seed quantity (kg/ha) in log		0.761**	2.408***
		(0.327)	(0.857)
_cons	-2.566	-6.040**	-25.575***
	(1.890)	(2.426)	(6.197)
No. of observations	321	321	459
F(11, 244)	5.72		
F(12, 244)		5.91	
F(12, 298)			5.29
Prob > F	0.0000	0.0000	0.0000
R^2	0.165	0.176	0.183

Notes: Estimates of the coefficient are shown with robust standard errors in parantheses. The dependent variable is the log of maize yield measured in tons per ha.
*p < 0.1, **p < 0.05, ***p < 0.01

As expected, inputs are critical determinants of yields at both locations. Pesticides and herbicides are particularly critical in Tamale ($p < 0.01$). The more a farmer spends on pesticides and herbicides the higher will be the maize yield. Farmers in Ghana commonly apply herbicides and pesticides during weeding as it is much cheaper than using manual labor (Ragasa et al. 2013). Here, these chemicals are a major production factor unlike in western Kenya, where smallholder farmers hardly use herbicides. Similarly, use of fertilizer inputs has a positive effect on maize yields at the two locations ($p < 0.05$). Despite the obvious benefits of fertilizers on crop yields, there is a limit to which they can be applied as fertilizers in SSA are very costly (Kijima et al. 2008).

However, spending more on labor has no effect on maize yields in Tamale. Farmers here are unlikely to employ manual labor for weeding or compost making, given their low application of organic amendments. Hence, any additional increase in labor cost does not necessarily result in a commensurate productivity gain in yield. In contrast, labor remarkably increases maize yield in Kakamega farmers' fields ($p < 0.01$). This result is consistent with findings from a study on the impacts of SRI adoption in Timor Leste where labor inputs were shown to increase rice yields (Noltze et al. 2013). Similar with SRI, organic amendments are an essential component of ISFM that require an immense amount of labor e.g. for compost preparation or biomass transfer. Also, farmers in Kakamega rely mostly on manual labor for other important agricultural practices such as weeding. As a result, there is a considerable expenditure on casual labor on their part.

When calculated treatment effects are depicted as in Table 19, we find that there is a marked yield effect both in Tamale and Kakamega. This implies that ISFM adopters would have significantly lower maize yield if they did not apply ISFM practices as depicted by the ATET of 16% for both Tamale and Kakamega. Although these results are specific to the two study areas, similar yield gains have been obtained with the application of other system innovations (Barrett et al. 2004; Noltze et al. 2013; Abdullai and Huffman 2014).

Table 19 Treatment effects for maize yield in Tamale, Ghana and Kakamega, Kenya

	Observations	With ISFM		Without ISFM		Treatment effect	% change
		POmean yield[1]	Robust Std. Err.	POmean yield[1]	Robust Std. Err.		
Tamale							
ISFM plots	36	1.009	0.129	0.870	0.044	ATET: 0.139*	15.98
All plots	321	1.030	0.098	0.856	0.025	ATE: 0.175**	20.44
Kakamega							
ISFM plots	369	0.914	0.096	0.788	0.045	ATET: 0.126**	16.02
All plots	459	0.894	0.091	0.773	0.042	ATE: 0.120**	15.57

Notes.[1]These yield predictions are displayed in logarithmic form. Back-converting to tons would result in inaccuracies due to inequality of geometric and arithmetic means (Noltze et al. 2013).
*$p < 0.1$, **$p < 0.05$

Similarly, there would be a yield increase on a randomly drawn plot as depicted by the positive and statistically significant ATE. The only notable difference is that in Kakamega, the significance of ATET is larger ($p < 0.05$). Additionally, as inferred from the models in Table 18, the positive effect of the technology here is as a result of transiting beyond the first step of the paradigm. The integration of ISFM components such as improved germplasm, inorganic fertilizer and organic input combinations, lime to correct acidity, terraces to conserve to soil on slopes and other good agricultural practices all act synergistically to improve AE and crop productivity.

Still, it is somewhat surprising that the magnitude of yield gain is more or less similar given that there seems to be more intensive use of ISFM practices in Kakamega. A possible explanation could be the variability in constraints to productivity arising from biophysical and topographical differences between the two sites. Although Kakamega’s soils are more fertile than soils in Tamale, acidity is a major constraint to crop productivity in the region (Kisinyo et al. 2014). The terrain also differs strikingly from that of Tamale as it is at higher altitude and the susceptibility to soil erosion is high (Waswa et al. 2013). Thus the use of lime or other alternative organic resources to rectify acidity and construction of terraces to control soil erosion are key ISFM practices that have to be incorporated for reasonable gain in crop yield and AE. Since Tamale is less afflicted with such constraints the first step of ISFM improves crop yields considerably. As posited by Sanginga and Woomer (2009), different technologies embedded within ISFM need to be applied according to the type of agro-ecological zone, which determines the soil characteristic of an area.

4.5.4 Assessment of the effects of ISFM on household income

To analyze income effects, we estimate a total household income model using OLS at the household level in the case of Kakamega. As the treatment variable, ISFM adoption, is not endogenous we again use a potential outcome model. Once more, the share of adopters in a farmer’s village is the instrument used to test for endogeneity. This instrument is not correlated with the outcome variable (P=0.139) and is also valid (P=0.129). In addition, it is adjudged to be a very strong instrument ($F(1,277)=115.818$, $P<0.001$). With regard to Tamale, endogeneity is confirmed; meaning that ISFM adoption is not random and could likely lead to selection bias in impact assessment (Kabunga et al. 2014). Thus an instrumental variable regression (ivregress) model is used instead. The share of adopters in a farmer's village is used as instrument as this is likely to correlate with adoption but not with household income. Indeed, the Wu-Hausman test confirms endogeneity (F(1,268)=6.280, P=0.013). The instrument used is deemed to be very strong (F(1,269)=121.978, P=0.001) and valid as well (P=0.651).

The results of the effects of various covariates on household income are shown in Table 20. Education of the household head in Kakamega is a key determinant of household income ($p < 0.01$) but surprisingly not in Tamale. Farmers with more years of formal schooling have a higher chance of securing formal employment, hence increasing the revenue streams available to the household. High levels of education and skills increase the propensity of farmers to diversify into non-farm sectors in effect reducing poverty levels (Abdulai and CroleRees 2001). Thus it is not surprising that off-farm occupation also has a very strong effect on income in Kakamega ($p < 0.01$). This is underlined by the high share of off-farm income in total income of the household at 57% (see Table 17). Perhaps the lower share of off-farm income in Tamale households (39%) could be a pointer to a lesser dependence on formal employment. Furthermore, the comparatively lower educational attainment among farmers in Tamale (see Table 15) given that education is linked to formal employment may be a possible reason as to why education does not influence household income. Nonetheless, off-farm income is still central to securing the economic welfare of Tamale households ($p < 0.01$). Off-farm activities are often more lucrative than on-farm activities in the smallholder sector (Noltze et al. 2013). Larger households in Kakamega are likely to have a higher income than smaller ones according to the model estimates ($p < 0.01$). This is plausible if the majority members of the household are of working age and can secure formal or informal employment.

Livestock not only play a crucial role in farming systems by providing manure; a key source of soil organic matter and nutrients, but are also an indicator of wealth in a household. Thus it is not surprising that livestock ownership highly influences household income in Kakamega ($p < 0.01$). Landholdings are also among the indicators of wealth for farming households (Abdulai and CroleRees 2001). In both cases, the estimates show a remarkable increase in income with the expansion of land cultivated ($p < 0.01$). As land is one of the primary factors of production, it follows that an increase in this resource will lead to higher income due to the scale of production. Land assets are one of the most important determinants of income (or the lack thereof) in smallholder farming systems (Mendola 2007). These asset endowments (e.g. land and livestock) have been associated with higher household incomes in SSA (Cunguara and Darnhofer 2011).

Table 20 Determinants of household income in Tamale, Ghana and Kakamega, Kenya

	Tamale	Kakamega
Variables	Model (Ivregress)	Model (OLS)
ISFM adoption (1=yes)	1.077***	0.091
	(0.377)	(0.209)
Age of HH head (years)	-0.001	-0.000
	(0.005)	(0.005)
HH head education (years)	0.020	0.076***
	(0.015)	(0.018)
HH size (no.)	0.022*	0.042**
	(0.012)	(0.018)
Off-farm occupation (1=yes)	0.424***	0.616***
	(0.118)	(0.133)
Tropical livestock units	0.011	0.112***
	(0.009)	(0.041)
Total cultivated area (acres)	0.025***	0.112***
	(0.008)	(0.031)
HHs with land title (1=yes)	0.074	0.116
	(0.201)	(0.139)
Access to formal credit (1=yes)	-0.026	0.367*
	(0.167)	(0.206)
Association membership (1=yes)	-0.039	-0.026
	(0.162)	(0.139)
HH location (1=urban/peri-urban)	0.231	0.282
	(0.176)	(0.158)
_cons	5.395***	4.311
	(0.317)	(0.416)
No. of observations	282	290
Wald $chi^2(11)$	94.86	
Prob > chi^2	0.0000	
F(11, 278)		13.41
Prob > F		0.0000
R^2	0.204	0.344

Notes: Estimates of the coefficient are shown with robust standard errors in parantheses. The dependent variable is the log of total household income measured in $US.
*p < 0.1, **p < 0.05, ***p < 0.01

Finally, access to credit has a positive influence on the capacity of households in Kakamega to increase their incomes. Unlike their counterparts, Kakamega farmers are often organized into vibrant and functional farmers' groups. Accordingly, they have access to microfinance institutions, which from the observation of the first author happen to be more active in

Kakamega than in Tamale. Furthermore, informal group-based rural financing models e.g. table ‘banking’, rotating savings and credit associations and merry-go-rounds seem to be prevalent in the area due to a high level of group formation (Kibaara 2006). Such schemes are very beneficial to farmers as they are mainly based on trust and more importantly eliminate the need for collateral, which seriously constrains smallholder farmer access to formal credit.

Concerning ATET and ATE, calculations from the Tamale site indicate a causal effect of ISFM adoption on total household income, whereas for Kakamega there is no such effect (Table 21). The income gain of 20% among ISFM adopters is quite considerable. This implies that if these farmers did not adopt ISFM their total household income would be less by the same magnitude. The results for Tamale are consistent with the findings of several studies, which have reported positive effects of agricultural technology adoption on household income or poverty reduction (Mendola 2007; Kijima et al. 2008; Noltze et al. 2013). One possible reason for the insignificance of ATET in Kakamega could be that farmers may be investing more in activities that entail the application of ISFM practices and less in other activities. However, maize constitutes a lower share of the total household income in Kakamega as compared to Tamale (Table 3). Thus ISFM-specific success may be difficult to discern as farmers’ livelihood strategies are often influenced by many other factors (Sanginga and Woomer 2009). Moreover, during the period these data relates to, farmers in Tamale benefited from fertilizer subsidies (at the rate of 50%); meaning they spent less on the most important inputs by half. The implication of this policy decision was that farmers were in a position to invest money they would otherwise have spent on fertilizer purchase on other economic activities. However, their counterparts in Kakamega did not enjoy similar subsidies. Although farmers here are better organized and may access credit through both formal and informal sources, this is still inadequate to counterbalance the costs pertaining to the uptake of ISFM practices. Hence, in the face of inadequate policy support for smallholder farmers, ISFM remains a somewhat costly venture.

Table 21 Treatment effects for household income in Tamale, Ghana and Kakamega, Kenya

	Observations	With ISFM		Without ISFM		Treatment effect	% change
		POmean yield[1]	Robust Std. Err.	POmean yield[1]	Robust Std. Err.		
Tamale							
ISFM HH	41	7.044	0.960	5.877	0.460	ATET: 1.167**	19.86
All HH	282	6.999	0.474	6.258	0.101	ATE: 0.741**	11.84
Kakamega							
ISFM HH	243	6.710	0.531	6.463	0.263	ATET: 0.246	
All HH	290	6.649	0.497	6.432	0.245	ATE: 0.217	

Notes.[1]These income predictions are displayed in logarithmic form. Back-converting to tons would result in inaccuracies due to inequality of geometric and arithmetic means (Noltze et al. 2013).
**$p < 0.05$

4.6 Conclusions and recommendations

In this study, we have used a counterfactual model (regression adjustment method and instrumental variable regression) to estimate average treatment effects on the treated of ISFM adoption on maize yield and total household income. We find that ISFM adoption leads to higher yields in both Tamale and Kakamega, and to higher incomes in Tamale. However, as the results attest, the income benefits are context-specific. In Kakamega, yield benefits did not translate into income benefits. This result suggests that the impact of the innovation is intertwined with the role the targeted crop plays in the wider scheme of the income diversification strategies of farmers. As shown by initial economic analysis, farmers at both locations have diverse income streams with off-farm income sources constituting a large share of this income.

The ISFM suite of technologies is envisaged by agricultural stakeholders to be a viable route through which improved household and regional food security, as well as increased incomes for smallholder farmers, may be achieved. However, evidence from this study shows that the effects of the ISFM innovation are location specific. Thus there is a need to carry out more cross-country comparative research on ISFM impacts, which is sorely lacking before it can be promoted widely. Also, caution should be applied when promoting innovations based only on yield effects, because these effects may not necessarily translate into higher incomes. For this reason, a holistic approach that carefully considers underlying issues such as input supply and produce markets, favorable policies, and well-functioning institutions, especially agricultural extension, is imperative.

Acknowledgements

This study was partly funded by Urban Food^plus project (FKZ: 031A242A) sponsored by the German Federal Ministry of Education and Research (BMBF) under GlobE-Research for Global Food Supply. This paper also benefited from comparative work in the rural-urban interface within FOR2432, funded by Deutsche Forschungsgemeinschaft (DFG). We are grateful for the logistical support and advice received from the University for Development Studies (UDS), the CSIR-Soil Research Institute, the Savannah Agricultural Research Institute (SARI), and the Kenya Agricultural Research and Livestock Organization (KARLO). We also thank the Ministry of Food and Agriculture (MoFA) officers, village elders and, last but not least, farmer participants in Kenya and Ghana for their cooperation. Finally, we gratefully acknowledge the German Academic Exchange Service (DAAD) for granting a scholarship to the first author.

References

Abdulai, A., and CroleRees, A. 2001. Determinants of income diversification amongst rural households in Southern Mali. *Food Policy* 26: 437–452.

Abdulai, A., and Huffman, W. 2014. The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics* 90: 26–43.

Agricultural Sector Development Support Programme. 2014. Household baseline survey report: Kakamega County. Ministry of Agriculture, Livestock and Fisheries, Nairobi.

Barrett, C.B., Moser, C.M., McHugh, O.V., and Barison, J. 2004. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *American Journal of Agricultural Economics* 86(4): 869–888.

Barrett, C.B. 2008. Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy* 33: 299–317.

Bationo, A., Kihara, J., Vanlauwe, B., Kimetu, J., Waswa, B.S., and Sahrawat, K.L. 2008. Integrated nutrient management: Concepts and experience from Sub-Saharan Africa. In *Integrated nutrient management for sustainable crop production*, ed. Aulakh, M.S., and Grant, C.A. 467–521. New York, NY: The Haworth Press, Taylor and Francis Group.

Becerril, J., and Abdulai, A. 2010. The impact of improved maize varieties on poverty in Mexico: A propensity score-matching approach. *World Development* 38: 1024–1035.

Bellwood-Howard, I., Häring, V., Karg, H., Roessler, R., Schlesinger, J., and Shakya, M. 2015. Characteristics of urban and peri-urban agriculture in West Africa. Results of an exploratory survey conducted in Tamale (Ghana) and Ouagadougou (Burkina Faso). International Water Management Institute (IWMI) Working Paper 163. Colombo.

Bellwood-Howard, I.R.V. 2014. Smallholder perspectives on soil fertility management and markets in the African Green Revolution. *Agroecology and Sustainable Food Systems* 38: 660–685.

Bolwig, S., Gibbon, P., and Jones, S. 2009. The economics of smallholder organic contract farming in tropical Africa. *World Development* 37: 1094–1104.

Braimoh, A.K., and Vlek, P.L.G. 2006. Soil quality and other factors influencing maize yield in northern Ghana. *Soil Use and Management* 22: 165–171.

Brand, J.E., and Halaby, C.N. 2006. Regression and matching estimates of the effects of elite college attendance on educational and career achievement. *Social Science Research* 35: 749–770.

Byerlee, D., and Heisey, P.W. 1996. Past and potential impacts of maize research in sub-Saharan Africa: A critical assessment. *Food Policy* 21: 255–277.

Corbeels, M., de Graaff, J., Ndah, T.H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H.D., and Adolwa, I.S. 2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems and Environment* 187: 155–170.

Cunguara, B., and Darnhofer, I. 2011. Assessing the impact of improved agricultural technologies on household income in rural Mozambique. *Food Policy* 36: 378–390.

Diagne, A., and Demont, M. 2007. Taking a new look at empirical models of adoption: Average treatment effect estimation of adoption rates and their determinants. *Agricultural Economics* 37(2-3): 201–210.

Gnahoua, J.-B.G., Ettien, D.J.B., N'zué, B., Ebah, C., Koné, B., de Neve, S., and Boeckx, P. 2016. Intensification pathway for improvement of smallholder cassava production systems in southern Côte D'Ivoire. *Experimental Agriculture* 52(1): 1–15.

Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S.,Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C., and Vanlauwe, B. 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems* 104(2): 191–203.

Giller, K.E., Rowe, E.C., de Ridder, N., and van Keulen, H. 2006. Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems* 88(1): 8–27.

Groote, H. de, and Kimenju, S.C. 2012. Consumer preferences for maize products in urban Kenya. *Food and Nutrition Bulletin* 33: 99–110.

Jaeztold, R., Schmidt, H., Hornetz, B., and Shisanya, C. 2005. *Farm management handbook of Kenya. Natural conditions and farm management information.* Nairobi: PHV Studios.

Jahnke, H.E. 1982. *Livestock production systems and livestock development in tropical Africa*. Kiel: Kieler Wissenschaftsverlag Vauk.

Jayne, T.S., Chamberlin, J., and Headey, D.D. 2014. Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. *Food Policy* 48: 1–17.

Kabunga, N.S., Dubois, T., and Qaim, M. 2014. Impact of tissue culture banana technology on farm household income and food security in Kenya. *Food Policy* 45: 25–34.

Kassie, M., Shiferaw, B., and Muricho, G. 2011. Agricultural technology, crop income, and poverty alleviation in Uganda. *World Development* 39: 1784–1795.

Khonje, M., Manda, J., Alene, A.D., and Kassie, M. 2015. Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Development* 66: 695–706.

Kibaara, B. 2006. Rural financial services in Kenya: What is working and why. Tegemeo Working Paper Series WPS 025/2006.

Kijima, Y., Otsuka, K., and Sserunkuuma, D. 2008. Assessing the impact of NERICA on income and poverty in central and western Uganda. *Agricultural Economics* 38: 327–337.

Kisinyo, P.O., Othieno, C.O., Gudu, S.O., Okalebo, J.R., Opala, P.A., Ng'etich, W.K., Nyambati, R.O., Ouma, E.O., Agalo, J.J., Kebeney, S.J., Too, E.J., Kisinyo, J.A., and Opile, W.R. 2014. Immediate and residual effects of lime and phosphorus fertilizer on soil acidity and maize production in western Kenya. *Experimental Agriculture* 50(01): 128–143.

Kristjanson, P., Neufeldt, H., Gassner, A., Mango, J., Kyazze, F.B., Desta, S., Sayula, G., Thiede, B., Förch, W., Thornton, P.K., and Coe, R. 2012. Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa. *Food Security* 4: 381–397.

Kuusaana, E.D., and Eledi, J.A. 2015. As the city grows, where do the farmers go?: Understanding peri-urbanization and food systems in Ghana - Evidence from the Tamale Metropolis. *Urban Forum* 26(4): 443–465.

Lambrecht, I., Vanlauwe, B., and Maertens, M. 2015. Integrated soil fertility management. From concept to practice in Eastern DR Congo. *International Journal of Agricultural Sustainability* 14: 100–118.

Lotter, D. 2015. Facing food insecurity in Africa. Why, after 30 years of work in organic agriculture, I am promoting the use of synthetic fertilizers and herbicides in small-scale staple crop production. *Agriculture and Human Values* 32: 111–118.

Maredia, M.K., Byerlee, D., and Pee, P. 2000. Impacts of food crop improvement research: Evidence from sub-Saharan Africa. *Food Policy* 25: 531–559.

Mathenge, M.K., Smale, M., and Olwande, J. 2014. The impacts of hybrid maize seed on the welfare of farming households in Kenya. *Food Policy* 44: 262–271.

Matuschke, I., and Qaim, M. 2009. The impact of social networks on hybrid seed adoption in India. *Agricultural Economics* 40(5): 493–505.

Mendola, M. 2007. Agricultural technology adoption and poverty reduction. A propensity-score matching analysis for rural Bangladesh. *Food Policy* 32: 372–393.

Nezomba, H., Mtambanengwe, F., Chikowo, R., and Mapfumo, P. 2015. Sequencing integrated soil fertility management options for sustainable crop intensification by different categories of smallholder farmers in Zimbabwe. *Experimental Agriculture* 51: 17–41.

Noltze, M., Schwarze, S., and Qaim, M. 2013. Impacts of natural resource management technologies on agricultural yield and household income: The system of rice intensification in Timor Leste. *Ecological Economics* 85: 59–68.

Nuss, E.T., and Tanumihardjo, S.A. 2011. Quality protein maize for Africa: Closing the protein inadequacy gap in vulnerable populations. *Advances in nutrition* 2: 217–224.

Odendo, M., Obare, G., and Salasya, B. 2009. Factors responsible for differences in uptake of integrated soil fertility management practices amongst smallholders in western Kenya. *African Journal of Agricultural Research* 4: 1303–1311.

Ragasa, C., Dankyi, A., Acheampong, P., Wiredu, A.N., Chapoto, A., Asamoah, M., and Tripp, R. 2013. Patterns of adoption of improved rice technologies in Ghana. *International Food Policy Research Institute Working Paper* 35: 6–8.

Rosenbaum, P.R., and Rubin, D.B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika* 70: 41–55.

Sanginga, N., and Woomer, P.L. 2009. *Integrated soil fertility management in Africa: Principles, practices and developmental process.* Nairobi: TSBF-CIAT.

Schlecht, E., and Buerkert, A. 2004. Organic inputs and farmers' management strategies in millet fields of western Niger. *Geoderma* 121: 271–289.

Shiferaw, B., Kassie, M., Jaleta, M., and Yirga, C. 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy* 44: 272–284.

Teklewold, H., Kassie, M., Shiferaw, B., and Köhlin, G. 2013. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics* 93: 85–93.

United Nations 2015. *World population prospects*. New York: United Nations.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L., and Sanginga, N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture* 39(1): 17–24..

Vanlauwe, B., Descheemaeker, K., Giller, K.E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., and Zingore, S. 2015. Integrated soil fertility management in Sub-Saharan Africa: Unravelling local adaptation. *Soil* 1(1): 491–508.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B., and Nolte, C. 2014. A fourth principle is required to define conservation agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research* 155: 10–13.

Vittinghoff, E., Glidden, D.V., Shiboski, S.C., and McCulloch, C.E. 2011. *Regression methods in biostatistics: Linear, logistic, survival, and repeated measures models* New York: Springer Science and Business Media.

Waswa, B.S., Vlek, P.L., Tamene, L.D., Okoth, P., Mbakaya, D., and Zingore, S. 2013. Evaluating indicators of land degradation in smallholder farming systems of western Kenya. *Geoderma* 195-196: 192–200.

Wooldridge, J.M. 2002. *Econometric analysis of cross section and panel data.* London: MIT Press.

Wooldridge, J.M. 2010. *Econometric analysis of cross section and panel data*. London: MIT Press.

Yiridoe, E.K., Langyintuo, A.S., and Dogbe, W. 2006. Economics of the impact of alternative rice cropping systems on subsistence farming: Whole-farm analysis in northern Ghana. *Agricultural Systems* 91: 102–121.

5 General discussion and recommendations

This chapter synthesizes the various aspects of ISFM adoption highlighted earlier while making a comparative assessment of the two study sites. It closes with policy recommendations and an outlook for future studies.

Study one revealed that the Kakamega AKIS communicates and disseminates ISFM knowledge more effectively than the Tamale AKIS, mainly because of adequate weak and strong ties to a diversity of actors (Chapter 2). Study two highlighted the importance of soil quality in influencing farmer adoption decisions (Chapter 3). At higher scales, demographic, socio-economic, and institutional factors were found also to be important drivers of ISFM adoption. In study three (Chapter 4), estimates showed that ISFM adoption has a positive causal effect on maize yield in Tamale and Kakamega. However, a positive effect on total household income was observed only in Tamale.

5.1 ISFM scale up/out in Kenya and Ghana

According to Douthwaite et al. (2003), scaling out entails innovation spread within the same stakeholder groups e.g. farmer to farmer, whereas, scaling up is the institutional expansion that incorporates all stakeholders, from farmers to policymakers, key in creating an enabling environment for innovation. The ISFM innovation has been lauded as being successful at the experimental level (in field trials), but so far there is little indication that its uptake has progressed beyond this scale (Kessler et al. 2016). Institutional bottlenecks contributed to the minimal impact of ISFM beyond the plot scale. According to Röling (2009a), innovation progress is determined by the nexus between institutional and technology development. In Africa, the lack of political support has resulted in weak institutions, which in turn have been unable to anchor and foster agricultural development (Gabre-Madhin and Haggblade 2004). Also, farming systems in SSA operate under different institutional contexts (e.g. market and policy) and are quite heterogeneous. Therefore, conditions for innovation uptake may differ across locations. In this study we compared two sites with divergent ISFM adoption levels. Drivers or constraints to ISFM uptake were remarkably similar in some cases whereas in others there was some differentiation.

Institutions have multiple roles to play in farming systems, which include exposure of farmers to new ideas and innovations through extension services, provision of credit, facilitating access to markets, provision of physical infrastructure and the creation of conducive policies (Matuschke and Qaim 2009; Vanlauwe et al. 2014). Ideally, institutional actors work in concert with farmers to effect change and drive innovation within the ambit of AKIS. A major aspect of AKIS examined in this study was the information flow between disparate actors (Chapter 2). The interaction between smallholder farmers and different stakeholders is considered a prerequisite for agricultural innovation (Röling 2009b; Triomphe et al. 2013). We found that smallholder farmers in the Kakamega AKIS more closely interacted with formal actors than their counterparts in the Tamale AKIS. This implied high intensity of interaction between smallholder farmers and other actors along the value-chain portends well for innovation uptake, particularly nuanced innovations such as ISFM. The AKIS framework envisages a higher capacity for innovation, learning and change in situations where multi-actor interactions are vibrant (Klerkx et al. 2012). Previous extension models, however, adopted a linear approach where innovations were transmitted from formal actors to farmers through a pipeline (Pascucci and De-Magistris 2011). It has been established that innovations transferred in this way are usually conveyed through weak ties (Matuschke and Qaim 2009; Thuo et al. 2013). This initiates awareness of a technology, which is a prerequisite step to its uptake (Lambrecht et al. 2014). The importance of weak ties for the awareness of complete ISFM was affirmed at both research locations. In the move towards complete ISFM, however, strong ties between farmers and other actors may be beneficial in internalizing new information acquired through weak ties. Roling (2009a), arguing from a farming systems perspective, suggests that approaches entailing collaboration between farmers and scientists are more effective than the traditional linear approaches.

Input and output markets are another dimension of institutions. Smallholder farmers can be linked to markets through actors that could be agribusinesses or private companies (Zoundi and Hitimana 2011). Linking smallholder farmers to markets or market actors is extremely important. However, as there are several risks involved given that markets in SSA are not highly developed, collaboration with other relevant stakeholders remains crucial as collective action might be necessary (Triomphe et al. 2013). In our case, market actors in Kakamega were more integrated into the AKIS than their counterparts in Tamale, as they had more ties to other actors and had a greater influence on information flow in the network (Chapter 2). Smallholder farmers could also be linked to markets by virtue of proximity to urban centers (Buerkert and Schlecht 2013). For instance, farmers residing in or close to cities have access to good road networks and communication infrastructure, which offer them quicker access to market centers thus eliminating the need for brokers or middlemen. The important role of markets in this regard was confirmed both in Kakamega and Tamale and was found to enhance ISFM adoption (Chapter 3). Farmers are likely to have access to not only output markets where they sell their produce but also input markets for the purchase of agro-inputs. However, the agro-input market in western Kenya and other parts of SSA is poorly developed due to the numerous problems faced such as lack of market access, low demand, limited market information, inadequate skills, and high transport costs (Chianu et al. 2011). This was affirmed by the very low influence of agrodealer actors regarding directing information flow in both AKIS (Chapter 2). Similarly, farmers in Tamale generally use traditional seed varieties as opposed to their counterparts in Kakamega due to weak seed markets. Thus entry-level adoption (the first ISFM component) is quite low (Chapter 3). Indeed, this situation presented a challenge in comparing ISFM impacts between the two locations (Chapter 4).

Lack of credit is a major hindrance to agricultural innovation uptake in SSA. Farmer associations are among the institutional innovations created to tackle this constraint (Matuschke and Qaim 2009). In addition, they offer essential training and skills to farmers. Indeed, farmer associations were found to be important drivers of ISFM adoption in the study areas (Chapter 3). One innovative aspect that contributes to the apparent cohesiveness of farmer associations in Kakamega is that they operate on the concept of group liability. Farmers in a group act as guarantors to each other invoking group pressure to ensure all members repay their loans (Giné and Karlan 2007; Quisumbing and Lauren 2010). This practice has been commonly applied by NGOs (e.g. One Acre Fund) and microfinance institutions in the study area. Farmer groups in Tamale hardly operate in this manner despite their strong presence in the AKIS. They are often formed in a hurried and ad-hoc manner mostly for purposes of credit acquisition and get disbanded soon after funds stop flowing. When used to their maximum potential, farmer associations can be a powerful promoting factor for the scale out of system innovations. Smallholder farmers in Kenya are fortunate to have benefited from the existence of extensive contract schemes such as the Kenya Tea Development Authority and Mumias Sugar Company schemes, entailing the production of cash crops such as sugarcane, tea, flowers and vegetables (Gabre-Madhin and Haggblade 2004; Ochieng 2007). These schemes, which initially were public sector organizations in multi-partite partnerships with other stakeholders, have provided smallholders with credit and other essential services over the years. These schemes have provided a viable route for entry into markets thus creating opportunities for smallholder farmers to innovate (Röling 2009a). This example from Kenya illustrates that there is a clear link between favorable domestic conditions and smallholder innovation.

The policy framework underpinning an agricultural system is crucial as it may create an enabling environment for agricultural innovation and its scaling up and out. There is ample evidence that supports the notion that African smallholder agriculture can be innovative and successful if supported by favorable policies (Gabre-Madhin and Haggblade 2004; Ochieng 2007; Triomphe et al. 2013). Unfortunately, African policy makers have for a long time relegated the smallholder farmer to the periphery, giving higher priority to the urban consumer as evidenced by the focus on cheap food imports (Röling 2009b; Hounkonnou et al. 2012). Policymakers (and researchers) to date favor linear-based and treadmill policy models that promote the rapid diffusion of science-based technological packages, often without adaptation, as they are envisaged to have high macro-economic impact (Röling 2009b; Röling 2010). But complex practices such as ISFM do not easily proscribe to diffusion processes (Roling 2009a). Such innovations demand internalization of underlying concepts, which may be enhanced with formal education or participation in training programs conducted within farmer associations (Chapter 3). Coupled with these are other externally instigated policies, which have had a debilitating effect on national institutions. The structural adjustment programs in SSA, for instance, led to the wide scale retrenchment of extension agents (Muyanga and Jayne 2006; Jama and Pizarro 2008). This greatly increased the farmer: extension agent ratio hence making it extremely difficult for the remaining agents to serve farmers adequately. Privatization and liberalization policies have led to the demise of previously vibrant public sector institutions at the expense of the smallholder farmer (Röling 2009a). The agricultural sectors in Ghana and Kenya have borne the repercussions of these policies more or less equally. That aside, agricultural policy frameworks in the two countries have in large measure taken divergent turns. Some of these policies have influenced the varied uptake of soil fertility innovations. The nature of interactions between policy makers and smallholders in the two agricultural systems in our study also contrasted remarkably. Policy actors, specifically the county government and chiefs, were the most influential in terms of directing information flow after extension agents in the Kakamega AKIS

(Chapter 2). Based on this evidence they can be considered to be powerful actors in this particular agricultural system. This, however, was not the case with the Tamale AKIS.

Partnerships and interactions between policy actors, smallholder farmers, and other actors have spurred key organizational, institutional and policy innovations and reforms in the Kenyan agricultural sector (Ochieng 2007). These policies or reforms touch on land adjudication, which has helped secure land tenure for smallholder farmers, cash crop production and intensive maize production (Williams 2003; Ochieng 2007). This has had a positive spill-over effect on innovation uptake. As a result, many farmers in western Kenya have been using fertilizers and improved maize seeds for much longer periods than their counterparts in Tamale. The recent push for policies to anchor agricultural intensification in northern Ghana has largely been unsuccessful due to discordance with the local politico-economic and social context (Nyantakyi-Frimpong and Kerr 2014). Hence the variation in underpinning policies and political structures has led to the divergent trajectories of agricultural innovation adoption and scale out in the two countries.

Finally, as knowledge is a major driving factor in AKIS, farmers should have timely access to relevant information. In this regard, mass media channels are well suited for agricultural information transmission along the entire agricultural product value chain at the study locations and possibly other similar areas.

5.2 Farm-scale opportunities and trade-offs for ISFM adoption

African smallholder farmers often operate in conditions where opportunities are scarce. Under such circumstances, a typical farmer may be forced to take hard decisions entailing trade-offs between resource use and availability. Consequently, the lack of opportunities constrains the adoption of agricultural innovations. The global agricultural treadmill describes a situation where local farmers are faced with unfair competition from farmers in developed countries that have received state support for decades hence can take advantage of economies of scale (Röling 2009b). A relevant example is the importation of chicken wings from the Netherlands to Ghana, a move that has seriously undercut local broiler markets (Hounkonnou et al. 2012). This situation further limits opportunities for smallholder farmers who are unable to access urban markets. Nonetheless, there is mounting evidence that farmers across Africa are adept at grabbing opportunities where they are available (Ayenor et al. 2007; Röling 2009a; Hounkonnou et al.

2012). The characteristics of individual farmers or households are likely to determine the extent to which they will utilize these opportunities. Age of the household head had a positive influence for both Tamale and Kakamega in terms ISFM uptake, although education was important only in Tamale (Chapter 3). These are among several socio-demographic factors that have been shown to drive uptake of soil fertility innovations (Marenya and Barrett 2007; Odendo et al. 2009; (Amirtham and Joseph 2011; Kassie et al. 2013).

Access to financial, human, land and production assets are a necessary condition for any farming enterprise. Resource-poor farmers are often constrained by limited availability of finances and/or labor, which severely limits their ability to make the most optimal production choices (Pannell et al. 2014). Economic incentives have been shown to result in the spontaneous adoption of soil fertility innovations by farmers in SSA (Buerkert and Schlecht 2013; Cordingley et al. 2015). Apart from monetary gains, farmers prioritize food security and trade-offs entailing use of on-farm resources (Cordingley et al. 2015; Vanlauwe et al. 2015). In our study, we found constraints or drivers to ISFM adoption to be remarkably similar at both locations whereby off-farm income, livestock ownership, and labor were key drivers (Chapter 3). The positive influence of off-farm income on the adoption of soil fertility innovations has been widely documented (Birungi and Hassan 2007; Kassie et al. 2013; Lambrecht et al. 2014). Thus it was not surprising that this also applied for ISFM. Having access to labor at key times is regarded as an important objective for every farmer especially when management practices are labor-intensive (Pannell et al. 2014). Previous studies focusing specifically on ISFM adoption in western Kenya and other areas have demonstrated the positive influence of livestock holdings (Marenya and Barrett 2007; Odendo et al. 2009; Adolwa et al. 2012). Livestock holdings, associated with the availability of manure, provide a positive complementarity with crop production in smallholder farming systems (Kristjanson et al. 2005; Rufino et al. 2007; Schlecht et al. 2011). The availability of manure and other organic amendments still pose a key constraint in the two agroecosystems as their use is rather low (Chapter 3). Moreover, there are often competing uses for such resources. For instance, farmers have been reported to utilize manure and nutrient rich soils for brick making rather than for crop production (Abdalla et al. 2012).

These assets are similarly crucial determinants of maize yield and household income in Tamale and Kakamega (Chapter 4). The only difference is that for maize production, social capital (farmer associations) is important in Tamale, whereas land and livestock resources are vital for household income in Kakamega. The main interest of agricultural stakeholders is whether agricultural innovations affect crop productivity and farmer livelihoods. At both study locations, ISFM increased maize yield among adopters, meaning that application of ISFM practices had a positive effect on maize yield (Chapter 4). However, there exist trade-offs that entail the use of production inputs such as fertilizers and labor, which may reduce net income from maize production. This seems to be a common feature of system innovations whereby, for instance in CA systems, adopting farmers tend to use more labor and fertilizer (Corbeels et al. 2014). Maize mostly plays a food security role in Kakamega thus commercialization of the crop is rather limited. As Kakamega is a sugarcane (*Saccharum officinarum*) belt zone, most farmers derive a good share of their income from cash crop sales, which is mostly sugarcane (Dose 2007). However, the effect of ISFM was only assessed on maize-based cropping systems. In the case of Tamale, the considerably lower intensification levels for maize production (Nyantakyi-Frimpong and Kerr 2014), means that it may yet be too early to ascertain the impact of complete ISFM. It is worth noting that farmers in Kakamega started using green revolution technologies way earlier than their counterparts in West Africa. These positive spill-over effects of technology use on food crops can be attributed to capital and input-intensive cash crop production systems that have existed since colonial times (Williams 2003; Gabre-Madhin and Haggblade, 2004; Ochieng 2007). Interestingly, households in Tamale practicing ISFM generated more off-farm income than non-ISFM households (Chapter 4). This underscores the importance of resource availability, especially where innovation uptake has still not reached the take-off point, as in Tamale. Rogers (2003) argues that innovators, the initial adopters in any given social system, mostly have access to adequate financial resources that could help buffer them against any unforeseen risks or losses. Income diversification, particularly from off-farm sources, is of key interest to policy makers given the complementarity between off-farm activities and agricultural development (Wanyama et al. 2010; Owusu et al. 2011). The impact of ISFM on household income showed a positive net effect for ISFM farmers in Tamale (Chapter 4). However, this was not the case in Kakamega.

At both study locations maize is primarily used to enhance food security. For more clarity, future research should consider including a cash or high-value crop such as sugarcane (Kakamega) or vegetables (Tamale) when estimating income effects of the ISFM innovation.

5.3 Soil quality as a driver of adoption and technical performance of ISFM

Farmers have a keen interest in the soil quality of their fields as this knowledge aids them in making decisions on input use or crops to grow. Ethnopedology, the study of soil knowledge and management systems of indigenous farming communities, helps us understand local approaches to soil perception, use, and management (Barrera-Bassols and Zinck 2003). Ethnopedological studies in Africa and Latin America indicate that farmer communities often rely on soil quality indicators such as soil texture (workability), soil organic matter (soil color), and soil depth to make important farming decisions (Barrios et al. 2006; Dawoe et al. 2012). Farmers' indicators of soil quality have largely been found to be congruent with scientific assessment of soil fertility or infertility. Dawoe et al. (2012), for instance, observed that farmers in the Ashanti area of Ghana were able to understand the role of macrofauna in nutrient cycling processes and their indicators for soil fertility such as soil color mirrored laboratory measurements for nitrogen, phosphorus, potassium and pH. We found soil carbon and pH to be important drivers of ISFM uptake (Chapter 3). While in Tamale an increase in soil carbon increased the likelihood of ISFM non-adoption the opposite effect was observed in Kakamega. The differentiated response to soil fertility by farmers in the two regions could be attributed to varying intensity of land use and resource allocation strategies. Agricultural practices are likely to be highly intensified in areas where population densities are high, and land sizes are small. The western region of Kenya has one of the highest population densities in Africa (Tittonell et al. 2005). Here farmers tend to apportion nutrients on all their fields particularly if they are resource-endowed (Vanlauwe et al. 2015). This relationship between resource availability and application of soil fertility innovations was similarly observed in northern Ghana.

A combination of factors including the intensive application of chemical fertilizers, leaching processes, and soil originating from non-calcareous parent material have led to high acidity, thus contributed to low crop production in western Kenya (Nekesa et al., 2005; Kisinyo et al. 2014). As such soil pH was found to be crucial here. This was reflected in the fact that an increase in one pH unit would increase the likelihood of non-adoption of ISFM measures. These results suggest that a shift towards acidity may drive farmers to apply soil ameliorants to avoid crop failure. Some of the locally available organic resources that can be used to rectify acidity include mulch from bushes or agroforestry trees (for instance *Tithonia diversifolia*), poultry manure, wood ash and an industrial waste available from local sugar mills known as filter press mud

(Figure 16). However, many farmers are not using organic amendments to correct acidity due to lack of awareness. Once this is overcome, labor constraints often hinder the use of organic material, whereas cash constraints prevent the purchase of lime.

The technical performance of an innovation, for example in terms of yield or nutrient use efficiency, is one of the fundamental conditions that have to be met for adoption to occur (Corbeels et al. 2014). Farmers will only adopt innovations that are better or at least equal to their current practices, are compatible with their problem-solving practices and do not create additional problems (Fujisaka 1994; Rogers 2003).

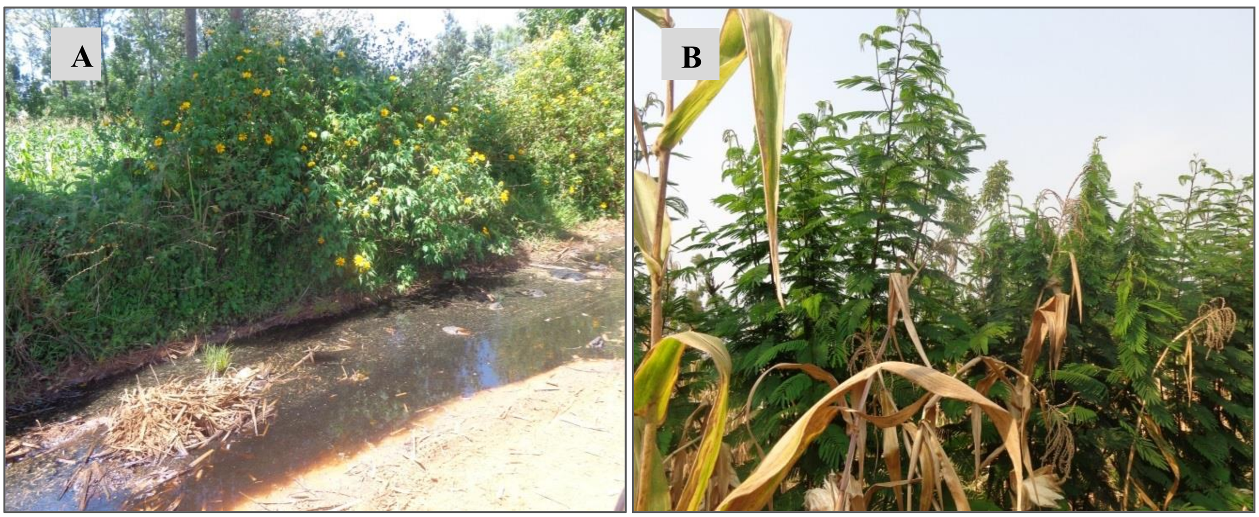

Figure 16 Some of the alternative options for liming in western Kenya; (A) filter mud (in the foreground) and *Tithonia diversifolia* fence (in the background) (B) *Calliandra calothyrsus*, an agroforestry tree

In the ISFM context, agronomic use efficiency (AE) is a key indicator of high performance. Preliminary experimental results in Tamale at Kamina barracks showed that AE of applied nitrogen (N-AE) did not increase with the incremental addition of ISFM components (*unpublished results*). Hence in this high input vegetable system, the first ISFM component gave a reasonable N-AE though the second component that included biochar was a better option due to the higher lettuce yield attained. Although there is a wide consensus that ISFM performance at plot level has been successful (Kessler et al. 2016), the effect of its different combinations on nutrient use efficiencies has yielded mixed results. Several studies have reported an increase in AE between ISFM combinations, particularly for mineral fertilizers and manure, in maize-based cropping systems (Vanlauwe et al. 2011; Otinga et al. 2013; Nezomba et al. 2015). Nevertheless, Rekha et al. (2005) observed a decrease in N-AE with incremental nutrient inputs in a vegetable cropping system. However, numerous such studies (Kimetu et al. 2004; Fening et al. 2009; Kiwia et al. 2009; Mugwe et al. 2009; Kihara et al. 2010), report ISFM combinations that are hardly used by farmers on the ground. Lambrecht et al. (2015) corroborated this view based on an ISFM study conducted in eastern DR Congo. As promising as these experimental results are, farmers in Tamale and Kakamega do not usually integrate similar organic resources (for instance *Crotalaria juncea, Calliandra calothyrsus and Tithonia diversifolia*) and intercrop sequences (e.g. maize-inoculated soybean) with other ISFM management practices. According to our field observations, Tamale farmers rarely incorporate such high-quality organic amendments. In most cases, maize stalks left behind after harvesting are incorporated into the soil mainly through livestock that trample on them as they feed. Again, there exists a trade-off between the use of available organic resources to fertilize the soil and as fodder for livestock. Although maize-bean intercropping is ubiquitous in many parts of East Africa, this combination is fraught with numerous disadvantages leading to underperformance (Sanginga and Woomer 2009). Only few farmers in Kakamega have integrated soybeans (*Glycine max* (L.) Merr) in their cropping systems as this crop is not locally marketable. Here too farmers seldom incorporate high-quality organic amendments some of which can be commonly seen on roadsides (Figure 16). Unfortunately, the experimental set-up in Tamale did not include manure or compost combinations but rather used biochar that is more of a soil conditioner than a nutrient source. The experiment also did not account for the effect of improved germplasm on N-AE as was done in a meta-analysis study by Vanlauwe et al. (2011). Perhaps due to these shortcomings, this experiment did not confirm the high technical performance, regarding nutrient use efficiency, which has been attributed to appropriate use of ISFM combinations. It would have been ideal to assess nutrient use efficiencies at the farm level using the sampled farmers, but it was difficult to estimate exact amounts of organic amendments used. A future study should carefully assess modalities of how such analysis can best be carried out.

5.5 Policy recommendations and outlook

Based on the results of this Ph.D. study, the several recommendations are proposed. Firstly, to enhance the functioning of AKIS, especially in Tamale, there is a need to promote multi-actor partnerships. This calls for the enhanced role of information intermediaries or innovation brokers whose main purpose would be to build linkages between disparate actors. Innovation brokers could be either privately or publicly funded organizations (e.g. farmer associations or NGOs) or individuals working as 'system builders'. The resulting increase in multi-stakeholder interactions will eventually improve knowledge dissemination and learning.

Secondly, policy measures aimed at alleviating structural problems currently afflicting the maize seed sector in Ghana should be put in place. It is important to factor within these policies the prevailing politico-economic structures under which farmers operate. There should also be a strong emphasis on improving distribution schemes of improved seed to ensure timely delivery to farmers.

Thirdly, governmental bodies at both locations should put in place credit schemes to boost farmers' financial assets in adherence to the 2014 Malabo Declaration by African heads of state and government to revamp the agricultural sector. This will enhance farmers' capacity to apply the full set of ISFM practices across their farms. It could help spur the use of improved seeds in Tamale or agricultural lime (to rectify acidity) in Kakamega.

Fourthly, as low soil carbon and acidity are major constraints to crop production in Tamale and Kakamega, respectively, extension and other change agents should focus on promoting farmer use of locally available organic amendments such as shea (*Vitellaria paradoxa* C.F.Gaertn) butter chaff (for Tamale) and *Tithonia diversifolia* (for Kakamega).

Fifthly, policies that have been enacted by the Kenyan and Ghanaian governments to tackle food insecurity over the years should continue to be promoted. One notable example of such policies is a nationwide programme initiated by the Kenyan government dubbed '*Njaa Marufuku (Chase Away Hunger)*'. As it is apparent from the results of this study, ISFM as an agricultural intervention has the potential to foster food security and improve economic welfare, particularly for the rural farming households.

Sixthly, it is important for policymakers and other stakeholders to consider the location specificity of ISFM before out-scaling the innovation. Based on this study, ISFM may be beneficial in terms of yield outputs but offer little economic incentives within the wider scheme of smallholder farming enterprises.

Future research may tackle the following aspects. Firstly, as ISFM has the potential to boost food production and improve livelihoods, further multi-locational studies will shed more light on context-specific factors transcending the socio-political, biophysical and economic spheres influencing system innovation awareness and adoption.

Secondly, cash crops should be incorporated when estimating impacts of ISFM. This means that focus should be extended beyond food crops as this research has shown that cash or high-value crops constitute a considerable share of household income. Vegetables such as pepper (*Piper nigrum* L.) or okra (*Abelmoschus esculentus* (L.) Moencha) could be considered in Tamale while sugarcane could be a suitable cash crop in Kakamega.

Thirdly, given the heterogeneity of African farming systems, there is a need to better identify best-best ISFM combinations for different areas. It may not be useful to impose a standard definition of the paradigm across-board. The challenge for future comparative studies will be how best to assess impacts between systems utilizing different ISFM options.

Fourthly, it would be interesting to investigate site-specific effects of ISFM combinations on N-AE using on-farm or farmer-led trials to enable better linkage with household and farm-level economic data.

References

Abdalla, I., Abdalla, S.B., El-Siddig, K., Moeller, D., and Buerkert, A. 2012. Effects of red brick production on land use, household income, and greenhouse gas emissions in Khartoum, Sudan. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 113(1): 51-60.

Adolwa, I.S., Okoth, P.F., Mulwa, R.M., Esilaba, A.O., Mairura, F.S., and Nambiro, E. 2012. Analysis of communication and dissemination channels influencing the adoption of Integrated Soil Fertility Management in western Kenya. *The Journal of Agricultural Education and Extension* 18(1): 71–86.

Amirtham, T., and Joseph, M.J. 2011. ICT and lifelong learning pedagogy for development and empowerment: An illustration from farmers in India. *Journal of Technology in Human Services* 29(1): 49–63.

Ayenor, G.K., Röling, N., van Huis, A., Padi, B., and Obeng-Ofori, D. 2007. Assessing the effectiveness of a Local Agricultural Research Committee in diffusing sustainable cocoa production practices: The case of capsid control in Ghana. *International Journal of Agricultural Sustainability* 5(2-3): 109–123.

Barrera-Bassols, N., and Zinck, J.A. 2003. Ethnopedology: A worldwide view on the soil knowledge of local people. *Geoderma* 111(3-4): 171–195.

Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Ramisch, J., Trejo, M.T., and Thomas, R.J. 2006. Indicators of soil quality: A South–South development of a methodological guide for linking local and technical knowledge. *Geoderma* 135: 248–259.

Birungi, P.B., and Hassan, R.M. 2007. Impact of alternative land management options on soil fertility and erosion in Uganda. *Agrekon* 46(3): 410–424.

Buerkert, A., and Schlecht, E. 2013. Agricultural innovations in small-scale farming systems of Sudano-Sahelian West Africa: Some prerequisites for success. *Secheresse* 24: 322–329.

Chianu, J., Mairura, F., and Ekise, I. 2011. Farm input market system in Western Kenya: Constraints, opportunities, and policy implications. In *Innovations as key to the green revolution in Africa*, ed. Bationo, A., Waswa, B., Okeyo, J.M., Maina, F., and Kihara, J. 879–886. Dordrecht, Netherlands: Springer.

Corbeels, M., de Graaff, J., Ndah, T.H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H.D., and Adolwa, I.S.

2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems and Environment* 187: 155–170.

Cordingley, J.E., Snyder, K.A., Rosendahl, J., Kizito, F., and Bossio, D. 2015. Thinking outside the plot: Addressing low adoption of sustainable land management in sub-Saharan Africa. *Current Opinion in Environmental Sustainability* 15: 35–40.

Dawoe, E.K., Quashie-Sam, J., Isaac, M.E., and Oppong, S.K. 2012. Exploring farmers' local knowledge and perceptions of soil fertility and management in the Ashanti Region of Ghana. *Geoderma* 179-180: 96–103.

Dose, H. 2007. Securing household income among small-scale farmers in Kakamega District: Possibilities and limitations of diversification. German Institute of Global and Area Studies (GIGA) Working Paper 41. Hamburg.

Douthwaite, B., Kuby, T., van de Fliert, E., and Schulz, S. 2003. Impact pathway evaluation: An approach for achieving and attributing impact in complex systems. *Agricultural Systems* 78(2): 243–265.

Fening, J.O., Yeboah, E., Gyapong, T.A., and Gaizie, E. 2009. On farm evaluation of the contribution of three green manures to maize yield in the semi-deciduous forest zone of Ghana. *African Journal of Environmental Science and Technology* 3(9): 234-238.

Fujisaka, S. 1994. Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agricultural Systems* 46(4): 409–425.

Gabre-Madhin, E.Z., and Haggblade, S. 2004. Successes in African agriculture: Results of an expert survey. *World Development* 32(5): 745–766.

Giné, X., and Karlan, D.S. 2007. Group versus individual liability: A field experiment in the Philippines. Center for Global Development Working Paper 111. Washington.

Hounkonnou, D., Dansou K., Kuyper, T.W., Leeuwis, C., Nederlof, E.S., Röling, N., Sakyi-Dawson, O., Traoré, M., and van Huis, A. 2012. An innovation systems approach to institutional change: Smallholder development in West Africa. *Agricultural Systems* 108: 74–83.

Jama, B., and Pizarro, G. 2008. Agriculture in Africa: Strategies to improve and sustain smallholder production systems. *Annals of the New York Academy of Sciences* 1136(1): 218–232.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., and Mekuria, M. 2013. Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change* 80(3): 525–540.

Kessler, C.A., van Duivenbooden, N., Nsabimana, F., and van Beek, C.L. 2016. Bringing ISFM to scale through an integrated farm planning approach: A case study from Burundi. *Nutrient Cycling in Agroecosystems* 105(3): 249–261.

Kihara, J., Vanlauwe, B., Waswa, B., Kimetu, J.M., Chianu, J., and Bationo, A. 2010. Strategic phosphorus application in legume-cereal rotations increases land productivity and profitability in western Kenya. *Experimental Agriculture* 46(01): 35-52.

Kimetu, J.M., Mugendi, D.N., Palm, C.A., Mutuo, P.K., Gachengo, C.N., Bationo, A., Nandwa, S., and Kungu, J.B. 2004. Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in Central Kenya. *Nutrient Cycling in Agroecosystems* 68(2): 127–135.

Kisinyo, P.O., Othieno, C.O., Gudu, S.O., Okalebo, J.R., Opala, P.A., Ng'etich, W.K., Nyambati, R.O., Ouma, E.O., Agalo, J.J., Kebeney, S.J., Too, E.J., Kisinyo, J.A., and Opile, W.R. 2014. Immediate and residual effects of lime and phosphorus fertilizer on soil acidity and maize production in western Kenya. *Experimental Agriculture* 50(01): 128–143.

Kiwia, A., Imo, M., Jama, B., and Okalebo, J.R. 2009. Coppicing improved fallows are profitable for maize production in striga infested soils of western Kenya. *Agroforestry Systems* 76(2): 455–465.

Klerkx, L., van Mierlo, B., and Leeuwis, C. 2012. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In *Farming systems research into the 21st century: The new dynamic*, ed. Darnhofer, I., Gibbon, D., and Dedieu, B. 457–483. Dordrecht, Netherlands: Springer.

Kristjanson, P., Okike, I., Tarawali, S., Singh, B.B., and Manyong, V.M. 2005. Farmers' perceptions of benefits and factors affecting the adoption of improved dual-purpose cowpea in the dry savannas of Nigeria. *Agricultural Economics* 32(2): 195–210.

Lambrecht, I., Vanlauwe, B., and Maertens, M. 2015. Integrated soil fertility management: From concept to practice in Eastern DR Congo. *International Journal of Agricultural Sustainability* 14(1): 100–118.

Lambrecht, I.,Vanlauwe, B., Merckx, R., and Maertens, M. 2014. Understanding the process of agricultural technology adoption: Mineral fertilizer in eastern DR Congo. *World Development* 59: 132–146.

Marenya, P.P., and Barrett, C.B. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy* 32(4): 515–536.

Matuschke, I., and Qaim, M. 2009. The impact of social networks on hybrid seed adoption in India. *Agricultural Economics* 40(5): 493–505.

Mugwe, J., Mugendi, D., Kungu, J., and Mucheru-Muna, M. 2009. Maize yields response to application of organic and inorganic input under on-station and on-farm experiments in central Kenya. *Experimental Agriculture* 45(01): 47-59.

Muyanga, M., and Jayne, T.S. 2006. Agricultural extension in Kenya: Practice and policy lessons. Tegemeo Institute of Agricultural Policy and Development, Egerton University Working Paper 26/2006. Nairobi.

Nekesa, A.O., Okalebo, J.R., Othieno, C.O., Thuita, M.N., Kipsat, M., Bationo, A., Sanginga, N., Kimettu, J., and Vanlauwe, B. 2005. The potential of Minjingu phosphate rock from Tanzania as a liming material: Effect on maize and bean intercrop on acid soils of western Kenya. *African Crop Science Conference Proceedings* 7: 1121-1128.

Nezomba, H., Mtambanengwe, F., Chikowo, R., and Mapfumo, P. 2015. Sequencing integrated soil fertility management options for sustainable crop intensification by different categories of smallholder farmers in Zimbabwe. *Experimental Agriculture* 51: 17–41.

Nyantakyi-Frimpong, H., and Kerr, R.B. 2014. A political ecology of high-input agriculture in northern Ghana. *African Geographical Review* 34(1): 13–35.

Ochieng, C.M.O. 2007. Development through positive deviance and its implications for economic policy making and public administration in Africa: The case of Kenyan agricultural development, 1930–2005. *World Development* 35(3): 454–479.

Odendo, M., Obare, G., and Salasya, B. 2009. Factors responsible for differences in uptake of integrated soil fertility management practices amongst smallholders in western Kenya. *African Journal of Agricultural Research* 4(11): 1303–1311.

Otinga, A.N., Pypers, P., Okalebo, J.R., Njoroge, R., Emong'ole, M., Six, L., Vanlauwe, B., and Merckx, R. 2013. Partial substitution of phosphorus fertiliser by farmyard manure and its localised application increases agronomic efficiency and profitability of maize production. *Field Crops Research* 140: 32–43.

Owusu, V., Abdulai, A., and Abdul-Rahman, S. 2011. Non-farm work and food security among farm households in Northern Ghana. *Food Policy* 36(2): 108–118.

Pannell, D.J., Llewellyn, R.S., and Corbeels, M. 2014. The farm-level economics of conservation agriculture for resource-poor farmers. *Agriculture, Ecosystems and Environment* 187: 52–64.

Pascucci, S., and De-Magistris, T. 2011. The effects of changing regional Agricultural Knowledge and Innovation System on Italian farmers' strategies. *Agricultural Systems* 104(9): 746–754.

Quisumbing, A.R., and Lauren, P. 2010. Promising approaches to address the needs of poor female farmers: Resources, constraints, and interventions. *World Development* 38(4): 581–592.

Rekha, K.B., Reddy, M.G., and Mahavishnan, K. 2005. Nitrogen and water use efficiency of bhendi (Abelmoschus esculentus L. Moench) as influenced by drip fertigation. *Journal of Tropical Agriculture* 43(1-2): 43–46.

Rogers, E.M. 2003. *Diffusion of innovations*, 5th edn. New York: Free Press.

Röling, N. 2010. The impact of agricultural research: Evidence from West Africa. *Development in Practice* 20(8): 959–971.

Röling, N. 2009a. Conceptual and methodological developments in innovation. In *Innovation Africa: Enriching farmers' livelihoods*, ed. Sanginga, P.C., Waters-Bayer, A., Kaaria, S., Njuki, J. and Wettasinha, C. 9–34. London, UK: Earthscan.

Röling, N. 2009b. Pathways for impact: Scientists' different perspectives on agricultural innovation. *International Journal of Agricultural Sustainability* 7(2): 83–94.

Rufino, M.C., Tittonell, P., van Wijk, M.T., Castellanos-Navarrete, A., Delve, R.J., de Ridder, N., and Giller, K.E. 2007. Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. *Livestock Science* 112(3): 273–287.

Sanginga, N., and Woomer, P.L. 2009. Integrated soil fertility management in Africa: Principles, practices and developmental process. Nairobi: TSBF-CIAT.

Schlecht, E., Dickhöfer,U., Predotova, M., and Buerkert, A. 2011. The importance of semi-arid natural mountain pastures for feed intake and recycling of nutrients by traditionally managed goats on the Arabian Peninsula. *Journal of Arid Environments* 75(11): 1136–1146.

Thuo, M., Bell, A.A., Bravo-Ureta, B.E., Okello, D.K., Okoko, E.N., Kidula, N.L., Deom, C.M., and Puppala, N. 2013. Social network structures among groundnut farmers. *The Journal of Agricultural Education and Extension* 19(4): 339–359.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., and Giller, K.E. 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. *Agriculture, Ecosystems and Environment* 110(3-4): 149–165.

Triomphe, B., Floquet, A., Kamau, G., Letty, B., Vodouhe, S.D., Ng'ang'a, T., Stevens, J., van den Berg, J., Selemna, N., Bridier B., Crane, T., Almekinders, C., Waters-Bayer, A., and Hocdé, H. 2013. What does an inventory of recent innovation experiences tell us about agricultural innovation in Africa? *The Journal of Agricultural Education and Extension* 19(3): 311–324.

Vanlauwe, B., Descheemaeker, K., Giller, K.E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., and Zingore, S. 2015. Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Soil* 1(1): 491–508.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., and van Asten, P. 2014. Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8: 15–22.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., and Six, J. 2011. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil* 339(1-2): 35–50.

Wanyama M., Mose, L.O., Odendo, M., Okuro, J.O., Owuor, G., and Mohammed, L. 2010. Determinants of income diversification strategies amongst rural households in maize based farming systems of Kenya. *African Journal of Food Science* 4(12): 754–763.

Williams, G. 2003. Studying development and explaining policies. *Oxford Development Studies* 31(1): 37–58.

Zoundi, S.J., and Hitimana, L. 2011. The challenges facing West African family farms in accessing agricultural innovations: Institutional and political implications. In *Innovations as* *key to the green revolution in Africa*, ed. Bationo, A., Waswa, B., Okeyo, J.M., Maina, F., and Kihara, J. 49–62. Dordrecht, Netherlands: Springer.

Appendix I

Exploratory Survey 2014/15

Introduction:

"Good morning/afternoon. We are conducting a survey on land use and farming practices to learn how new agricultural technologies could assist farmers in (Tamale/Kakamega). We would like to ask you some questions that should take no more than half an hour of your time. We would like to understand how food and livestock are grown and used in this region.

Your name will not appear in any data that is made publicly available. The information you provide will be used purely for research purposes. Do you consent to be part of this study? If there are questions that you would prefer not to answer then we respect your right not to answer them."

Has consent been given? Yes *(tick)* [_]

City: Kakamega [_] Tamale [_]

	Name	Code	Date (day/month/year)
Interviewer:	__________________	[_ _]	_ _/_ _/_ _ _ _
Data entered by:	_________________	[_ _]	_ _/_ _/_ _ _ _

GPS coordinates of point (location): Latitude: _____° _____' _____'' N

Longitude: _____° _____' _____'' W

Area name: ____

Notes on location:

Name of respondent? ____________________________

Exploratory Qualitative Research Activities (RAAKS):

Problem definition exercise

- Which activity are you involved in as relates to agriculture?
- How diverse is your area of activity (with respect to farming systems, agro-ecological zones, social groups, etc.)?
- Which other agricultural actors are involved in this area?
- What general problem or problems can you identify?
- What is the history of the problem?
- What are possible causes of the problem?
- Are these problems urgent?

Actor objective sheet

- What are your objectives as an agricultural stakeholder?
- What is your contribution to the agricultural development process?
- Who do you think are beneficiaries of your objectives?
- What technologies and/or activities are being developed or implemented as a result of each objective?
- Which actors are crucial to implementing each objective?

- Is there a shared objective?

A prime mover septagram

- Who do you see as a prime mover/s[7] in the system?
- Which of these prime movers exert the strongest influence and, which the least?
- Who could change the situation and would be interested in doing so? Why?

Info-source-use exercise (integrated with impact analysis sheet)

- What sources and type of information do you use regularly?

Type of information used	**Are they available in your network**	**Most important sources**
Strategic		
Operational		
Technical		
Market		
Policy		

[7] Those who give leadership and have the most influence on what transpires in a system

In-depth interviews of select farmers

These pointers will be linked to the RAAKS and SNA methodology:

- What is the reality on the ground? Is soil fertility a primary, secondary or tertiary issue? If it is a primary issue then ISFM can be introduced.
- Potential information sources as revealed by:
    - Types of soils
    - Type of ploughing employed by farmer
    - Type of pesticides or herbicide used by farmer
    - Type of labor used by farmer e.g. is it group or reciprocal labor?
- Innovations or practices used by farmer:
    - Improved germplasm/seed
    - Fertilizer
    - Manure/compost/organic material
    - Recommended spacing
    - Timing of fertilizer application
- [While mapping farmer networks assess how farmers implicitly seek for information to solve their problems (limit to agricultural problems). Which actors do farmers turn to when in need of information? This should come out in the course of a discussion with a farmer or groups of farmers.] It is better if the farmer implies rather than information being extracted from them.
- What techniques, particularly soil fertility management interventions, are extension farmers transferring to farmers? What are they telling farmers? It will be useful to attend and record some extension sessions.
- How do farmers interpret information received from extension agents? How do they integrate it with own knowledge?
- Identify possible gaps between knowledge of extension agents and that of farmer interpretation.
- What is the situation on farmers' farms? This should be described in positive terms as much as is practically possible.
- What are current agricultural systems as practiced by farmer? What was practiced prior to first intervention?

The Social Network Analysis (SNA):

Who do you exchange important agricultural information with? (For question 3 and 4 mark with X appropriately)

1. With which actors do you discuss important agricultural information?	2. Role	3. To whom have you given information on an innovation?	4. From whom have you received information on an innovation?	5. Phone number of actor	6. Address of actor	7. How frequent are the contacts?	8. Are contacts formal or informal?

9. Who initiated these contacts?

____

____

10. What resources are available to maintain these contacts?

____

____

Appendix II

Survey Questionnaire 2014/2015

Urban Food^Plus

SPONSORED BY THE Federal Ministry of Education and Research

Introduction (interviewer/translator):

"Good morning/afternoon. We are a research team, conducting a survey on land use and farming practices to learn how new agricultural technologies could assist farmers in Tamale/Kakamega. We would like to ask you some questions. We would like to understand how food and livestock are grown and used in this region and the issues that you face regarding food production, livestock production and soil, water and land management.

Your name will not appear in any data that is made publicly available. The information you provide will be used purely for research purposes; your answers will not affect any benefits or subsidies you may receive now or in the future. Do you consent to be part of this study? If there are questions that you would prefer not to answer then we respect your right not to answer them."

Has consent been given? Yes *(tick)* [_]

Interview/Household ID: [_ _ _] *(to be entered only AFTER completion of survey)*

City: Tamale [_] Kakamega[8] [_]

	Name	Code	Date (day/month/year)
Interviewer:	__________________	[_ _]	_ _/_ _/_ _ _ _

Sampling unit (grid cell ID): _______________ Code: [_ _ _]

GPS coordinates of corresponding household: Latitude: _____° _____' _____'' N

(Location of house/residence) Longitude: _____° _____' _____'' W/E

Area name or village: ____

Notes on household and location:

Backyard/Urban space [__] Open/Peri-urban space [__] Village [__]

Farmer contact:________________________

Soil sample taken: [_] Yes (tick)

Notes on soil samples (pg. 23/last page)

[8] Some aspects of the questionnaire e.g. units for maize bags and currency were adjusted to fit the site/city. Dates and duration also differed between sites as interviews were conducted at different times.

Section 1: Respondent and household composition

1.1 What is your name? ___________________________

1.2 Are you a decision maker of this household? Yes [_] No [_]

=> *If no*: who is the decision maker of your household? _______________________

1.3 What is your nationality (i.e. country of citizenship?)

[_] country of residence [_] other: ______________________________________

=> Any HH member listed above with another nationality? [_] Yes: ______________

1.4 What is your ethnic affiliation? ____

1.5How long have you been a resident in this town?

Since [_ _ _ _] *(year moved here)*

=> If current city is not the home town, where is your hometown? ____________________

1.6 If farming is your main activity what is the main reason for engaging in it?____

____

____

____

____

____

1.7 How many people live together with you in this household (i.e. those sharing the same house and regularly taking meals in the last 12 months)? List all the adult household members i.e. 16 years and above. For children, number is enough.

Name of HH member (start with respondent)	Relation to HH head **Code A**	Gender **(0=male; 1=female)**	Age **(years)**	Marital status **Code B**	Education level **Code C**	Religion **Code D**	Years of farming experience	Farm labour participation **Codes E**	Main occupation **Code F**	Yearly net income in Kshs/Ghc if **NOT** farming	2nd important occupation **Code F**	Yearly net income in Kshs/Ghc if **NOT** farming	Other income sources **Code G**	Yearly net income from other sources (Kshs/Ghc)
1.														
2.														
3.														
4.														
5.														
6.														
7.														
8.														
9.														
10.														
11.														
12.														

Codes A
1 Household head
2 Spouse
3 Son/daughter
4 Parent
5 Son/daughter in-law
6 Grand child
7 Other relative
8 Other, specify……

Codes B
1 Married living with spouse
2 Married but spouse away
3 Divorced/separated
4 Widow/widower
5 Never married
6 Other, specify………

Code C
0 None (illiterate)
1 Basic (can write and read)
2 Lower primary (1-4)
3 Upper primary (5-8)
4 Junior secondary (9-10)
5 Senior secondary (11-12)
6 Vocational training
7 College
8 University
9 Other, specify …

Codes D
0 No religion
1 Moslem
2 Christian
3 Traditional
4 Other, specify

Code E
0 None
1 Full time
2 Part-time
3 Weekends and holidays
4 Other, please specify …………….

Codes F
0 No occupation
1 Farming (crop and/or livestock)
2 Herds boy/girl
3 Housekeeping
4 Casual labourer on another farm
5 Non-farm business (shops, trade, tailor, etc)
7 Salaried employment
8 Other, specify………
9 Student

Codes G
1 Rented out land
2 Rental income (e.g. from renting tractor, animals for traction, houses)
3 Sale of dung cake for fuel
4 Sale of own trees (firewood, etc)
5 Own business
6 Pension income
7 Drought relief
8 Remittances (sent from non-resident family and relatives)
9 Marriage gifts (e.g., dowry)
10 Other, specify ……………..

Section 2: Farm characteristics, production and irrigation

2.1 How many fields do you have (circle total number in first column of table below)?

Field	Crop	Field location 1=Within homestead 2=Outside homestead, same village 3=Outside homestead, different village	If not within homestead, walking time to field (min)	Used since (no. years)	Approx. size (acres)	Is this the most important field? (tick) Why?	Soil fertility 1=Poor 2=Medium 3=Rich	Soil type* 1=Clay 2=Loamy 3=Sandy 4=Other	Slope 1=Gentle slope (flat) 2=Medium slope 3=Steep slope	Specify ownership (e.g. land title, leased out, rented, share-cropped, etc.)	Tilling method 1=manually 2=using bullocks 3=tractor 4=depends on the crops grown there
1											
2											
3											
4											
5											
6											
7											
8											

*Is there local name for soil type?

2.2 Have you had any problem with flooding on your field(s)? Please explain!

____

2.3 What crops did you grow in the last short-rain and long-rain seasons?

Where do you get your irrigation water from, and what methods do you use for irrigating your crops?

In previous rainy season		In previous dry season			
Production (years)		Production (years)		Irrigation	
Crop Long rain		Crop Short-rain or dry period		Water source 1=rainwater 2=river 3=piped water 4=wastewater 5=ponds 6=well/spring 7=other (specify)	Irrigation method 1=rain-fed 2=pump/pipes 3=watering cans 4=runoff irrigation 5=other (specify)

Notes/additions on cropping patterns and irrigation practice: Tamale has one wet season from April/May-September and a dry season (October-May). Kakamega has two wet seasons from March/May and September/December .

2.4 Crop activities:

Instruction: Focus on <u>maize</u>. Use the crop code sheet. The criterion for selecting fields from which to collect soil sample is based on fertility (poor and rich) or importance to the farmer.

i. *Tell us about your crop production and management practices in the previous long-rain and short-rain seasons (Kakamega only).*

<u>Field ID</u>	Crop Code (See code sheet)	Area under this crop (acres)	Season (LR or SR)	Time of Sowing		Spacing 0=ad-hoc 1=recom mended	Spatial arrangement **Code A**	If there is spatial arrangement, with which crop? (See code sheet)	Weeding 0=none 1=once 2=twice 3=thrice 4=other	Local adaptation			Harvest		Sales [Skip to next row if not sold]		Revenue	
				Month	Week					Practices employed **Code B**	Why? **Code C**	How? (Go to Notes)	Qty	Unit	Qty	Unit	Average Price (Kshs/Ghc)	Gross sales (Kshs/Ghc)

UNIT codes:
1=90 kg bag
11=50 kg bag
2=Kgs
3=Litre
9=Gorogoro
10=Tonnes
12=Debe
4=Crate
5=Numbers
6=Bunch(bananas)
13=Grams
7=25 kg bag
8=10 kg bag
14=Wheelbarrow
15=Cart
19=Donkey load
20=Donkey cart load
16=Canter
17=Pick-up
18=2kg bag
21=Hand cart load
22=Head load
24=Cocoa/mini sack
23=Maxi sack
25=Other

Code A
0=None
1=Intercropping
2=Crop rotation
3=Relay cropping
4= Sequential cropping
5= Catch cropping

Code B
0=None
1=Lime application
2=Heaping or ridging
3=Crop residue use
4=Targeted manure application
5=Minimum tillage
6=Mulching
7=Burning
8=Staggered planting
9=Use of drought-resistant crop varieties
10=Treatment of plant material
8=Other (Specify..)

Code C
1=To increase soil fertility
2=To reduce acidity
3=To conserve soil moisture
4=To reduce soil erosion
5=To reduce weeds
6=To reduce pests
7=To cope with late rainfall
8=To curb soil crusting
8=To break dormancy of seeds
9=To create adequate depth for crops
10=Other (Specify..)

ii. Which crop production inputs did you use in the previous long-rain and short-rain seasons (Kakamega only)?

Field ID	Crop Code (See code sheet)	Season (LR or SR)	Seed use				Mineral Fertilizer Use								Organic Fertilizer Use					Expenditure on pesticides (herbicides/ insecticides/ fungicides) Kshs or Ghc
			Seed type? 1=Local 2=Improved 3=Mixed 4=Saved seeds	Qty	Unit	Price per unit Kshs/ Ghc	1st Mineral fertilizers				2nd Mineral fertilizers				Type (Code below)	If type=3, type of plant used? (Code below)	Qty	Unit	Price per unit Kshs/Ghc	
							Type (Code below)	Qty	Unit	Unit price Kshs/Ghc	Type (Code below)	Qty	Unit	Unit price Kshs/Ghc						

UNIT codes:
1 =90 kg bag (Jute)
11=50 kg bag (Makola)
2 =kgs
3 =litre
9 =gorogoro
10 =tonnes
12 =debe
4 =crate
5 =numbers
6 =bunch(bananas)
13 =grams
7 = 25 kg bag
8 = 10 kg bag
14 = wheelbarrow
15 =cart
19 =Donkey load
20 = Donkey cart load
16 =canter
17 = pickup
18 = 2kg bag
21 = Hand cart load
22 = Head load
24= Cocoa/mini sacks
23=Maxi sacks
25= Other (specify)

FERTILIZERS
8=NPK (20:20:0)
9=NPK (17:17:0)
10=Ammonia
11=NPK (23:23:0)
12=NPK (17:17:17)
13=NPK (15:15:15)
14=NPK (18:14:12)
15=NPK (14:14:20)
16=UREA (46:0:0)
17=Folia Feeds
18=Magmax Lime
19=Rock Phospate
20=Kero Green
21=Mavuno-Basal
22=Mijingu 1100
23=Mavuno-Top Dress
32=NPK (23:10:5)
24=DAP
25=MAP
26=TSP
27=SSP
28=DPS
29=CAN (26:0:0)
30=ASN (26:0:0)
31=SA (21:0:0)
33=Other specify (___)

MANURE
0= None
1=Farmyard manure
2=Animal Manure
3=Green Manure
4=Compost
5=Biochar
6=Other specify
(__________)

TYPE OF PLANT
1=Tithonia
2=Calliandra
3=Other specify
(_________)

iii. Production and utilization of crop produce not included in the cropping system above (i.e. during the past short and long-rain season):

Field ID	**Crop ID**	Input use			Quantity produced	Production units **Code B**	Quantity consumed	Quantity sold	Price (Kshs/Ghc)	Total sales (Kshs/Ghc)
		Type **Code A**	Quantity	Expenditure						

2.5 What other inputs did you use in the past wet/long and dry/short season for your farm production? Please estimate your expenditures (in local currency), where applicable.

	Past long-rain season	Past short-rain season	Total expenditure (Kshs/Ghc)
Transportation costs	[_]	[_]	
Sacks	[_]	[_]	
Labor (farm workers; total wages/cash expenditures)	[_]	[_]	
Hired equipment/tractor	[_]	[_]	
Hired oxen	[_]	[_]	
Veterinary medicines & vaccines	[_]	[_]	
Fodder & poultry feed	[_]	[_]	
Cost of rented land	[_]	[_]	
Other (specify)	[_]	[_]	

Code A
1=Chemical fertilizer
2=Manure
3=Compost
4=Biochar
5=Seeds
6=Herbicides
7=Pesticides
8=Other (Specify…)

Code B
1=90 kg bag
11=50 kg bag
2=kgs
3 =litre
4=crate
9 =gorogoro
5=numbers
6=bunch(bananas)
13=grams
7= 25 kg bag
12=debe
10=tonnes
8=10 kg bag
14= wheelbarrow
15=cart
19=Donkey load
20= Donkey cart load
16=canter
17= pickup
18= 2kg bag
21= Hand cart load
22= Head load
24= Cocoa/mini sacks
23=Maxi sacks
25= Other (specify)

2.6 If you own livestock, please list the no. of animals that you own:

Animal type	Current Stock 2014	Value (Kshs/Ghc)	Stock changes in the last short and long-rain seasons							
			Died	Consumed	Bought	Value per head (Kshs/Ghc)	Gifts in	Gifts out	Sold	Value (Kshs/Ghc)
Cattle										
1. Indigenous cows										
2. Hybrid cows										
Goats										
Sheep										
Other livestock										
3. Donkeys										
4. Pigs										
5. Chicken										
6. Guinea fowl										
7. Rabbits										
8. Bee hives										
9. Turkeys										
10. Ducks										
11. Geese										

2.7 Production and utilization of livestock products (in the last short and long-rain seasons or last 12 months)

Livestock products	Quantity produced	Units of production **Codes A**	Frequency of production **Codes B**	Number of productive months	Quantity consumed	Quantity sold	Price (Kshs/Ghc)	Total revenue (Kshs/Ghc)
Milk								
Eggs								
Animal skin								
Honey								

Codes A:
1=Litres;
2=Kg;
3=Pieces;
4=Trays;
5=Other, specify……….

Codes B:
1=Daily;
2=Weekly;
3=Monthly;
4=Every 3 months;
5=Every 4 months;
6=Every 6 months;
7=Annually;
8=Other, specify……..

Section 3: Household assets, amenities and income

3.1 Which of the following items are owned by anyone in your household?

Asset	ID	No. **purchased** in the last 12 months	No. **currently** owned	Year of **purchase**, if not in the last 12 months	Asset	ID	No. **purchased** in the last 12 months	No. **currently** owned	Year of **purchase**, if not in the last 12 months
Tractor	1				Bicycle	17			
Trailer	2				Radio/ Tape-recorder	18			
Vehicle	3				Car Batteries	19			
Motorcycle	4				Television	20			
Carts	5				Mobile Phones	21			
Watering cans	6				Water tanks	22			
Wheelbarrows	7				Grinders	23			
Ploughs	8				Beehives	24			
Borehole	9				Milking churns	25			
Well	10				Furniture	26			
Sickle	11				Mosquito nets	27			
Hand hoe	12				Other specify	28			
Chaff cutter for fodder	13				Forked Hoe	29			
Machette /Panga	14				Slasher	30			
Knapsack sprayer	15				Axe	31			
Solar Panels	16								

3.2 Do you have electricity access at home? Yes [_] No [_]

3.3 What is the distance to your drinking water source from your house?
Specify source (e.g. well, public water tap): ______________________
Distance: ________ minutes _________ km

Section 4: Knowledge and adoption of improved maize varieties, inorganic fertilizer and management practices

4.1 Please fill the following Table for all improved varieties of maize the farmer knows (also those s/he does not plant her/himself)

Varieties known (**Variety Codes**)	Type of variety (**0**=Local; **1**=Modern)	For all **modern** varieties known			If **NO**			
		When (year) did you first hear about the variety?	From whom/where did you first hear about it? Rank up to three **Code A**	Ever planted the variety? **(0=no; 1=yes)**	Give reasons **(Code B,** rank 3**)**	Ever seen the variety growing? (**0**=No; **1**=Yes)	Will you plant variety in future? (**0**=no; **1**=yes)	*If NO*, why not? (**Code B**, rank3)

Maize Variety Codes
38=303
39=DK 8031
40=DK 8998
41=FRC 4251 IR
42=SC Simba
43=WH 402
44=502
45=513

Maize Variety Codes
21=Obatanpa
22="white maize" (local)
23="red maize" (local)
24=Mamaba
25=Pannar
26=62-10
27=614
28=HB 516
29=HB 624
30=HB 513
31=Western 507
32=WH 403
33=WH 505
34=WH 507
35=Modern variety (unspecified)
36=Local variety (unspecified)
37=Other maize variety (specify..)

Code A
1=Government extension
2=Farmer-based organization
3=NGO
4=Research center
5=On-farm trials/demos/field days
6=Seed/grain stockist
7=Another farmer/neighbor
8=Radio/newspaper/TV
9=Farmer magazine
10=Mobile phone updates
11=Drama/skit
12=Other, specify…...…

Code B
1=Cannot get seed at all
2=Lack of cash to buy seed
3=Susceptible to field pests/diseases
4=Susceptible to bird attack
5=Susceptible to storage pests
6=Poor taste
7=Cannot get credit
8=Low yielding variety
9=Poor prices
10=No market
11=Requires high skills
12=Seeds are expensive
13=Requires more rainfall
14=Labor intensive
15=Other, specify

4.2 For all MODERN varieties known in Table 4.1, please fill the following table.

Maize varieties known **(copy from Table 4.1)**	Year first planted	Reasons for Planting **Code B**	Main source of first seed **Code C**	Means of acquiring first seed **Code D**	Planted variety in 2013LR* (0=N0; 1=Yes)	If No, why not (**Code A**, rank 3)	Before adopting had you seen the variety in the field? (0=N0; 1=Yes	If Yes, where (**Codes E**, list 2)	If yes, was the plot located in your village (0=No; 1=Yes)

*In Tamale, 2011 and 2012

Code A
1=Cannot get seed at all
2=Lack of cash to buy seed
3=Susceptible to field pests/diseases
4=Susceptible to bird attack
5=Susceptible to storage pests
6=Poor taste
7=Cannot get credit
8=Low yielding variety
9=Poor prices
10=No market
11=Requires high skills
12=Seeds are expensive
13=Requires more rainfall
14=Labour intensive
15=Other, specify

Codes B
1=No other variety availabl
2=Best adapted variety
3=High yields
4=……. … (*Please fill name*) recommended it to me
5=Other, specify
6=Drought toleranc
7=Early maturity
8=Sweet taste/ aroma
9=Good flour quality
10=Brewing quality
11=High price

Code C
1=Research
2=Extension officer
3=Bought from local seed producers
4=Bought from local trader or agro-dealers
5=Farmer to farmer seed exchange (relative, friend, etc)
6=Provided by NGOs
7=Other (specify)…

Code D
1=Gift/free
2=Borrowed seed
3=Bought with cash
4=Payment in kind
5=Exchange with othe seed
6=Other, specify…..

Codes E
1=Parent
2=Child
3=Brother/sister
4=Grandparent
5=Grandchild
6=Nephew/Niece
7=Uncle/aunt
8=Cousin
9=Same family lineage
10=Mother/father in-law
11=Brother/sister in-law
12=Other relative
13=Fellow villager/Neighbor
14=Attend same church/mosque
15=Professional/business colleague
16= Research station
17=. Demo/trial plot
18= Agricultural show

4.3 Please fill the following table for all types of fertilizer the farmer knows.

Inorganic fertilizer Known **Code A**	When (year) did you first hear about the fertilizer	From whom did you first hear about it? **Code B**	Ever used the fertilizer? (0=no; 1=yes)	If NO, give reasons (**Code C**, rank 3)	Will you use fertilizer in the future (0=no;1=yes)	If NO, why not? (**Code C**, rank3)

Code A
8=NPK (20:20:0)
9=NPK (17:17:0)
10=Ammonia
11=NPK (23:23:0)
12=NPK (17:17:17)
13=NPK (15:15:15)
14=NPK (18:14:12)
15=NPK (14:14:20)
16=UREA (46:0:0)
17=Folia Feeds
18=Magmax Lime
19=Rock Phospate
20=Kero Green
21=Mavuno-Basal
22=Mijingu 1100
23=Mavuno-Top Dress
24=DAP
25=MAP
26=TSP
27=SSP
28=DPS
29=CAN (26:0:0)
30=ASN (26:0:0)
31=SA (21:0:0)
32=NPK (23:10:5)
33=Other (Specify….)

Code B
1=Government extension
2=Farmer-based organisation
3=NGO
4=Research centre
5=On-farm trials/demos/field days
6=Seed/grain stockist
7=Another farmer/neighbor
8=Radio/newspaper/TV
9=Farmer magazine
10=Mobile phone updates
11=Drama/skit
12=Other, specify…...…

Code C
1=Cannot get fertilizer at all
2=Lack of cash to buy fertilizer
3=Causes acidity
4=Lack of information on how to use
5=Poor prices
6=No market
7=Requires high skills
8=Fertilizers are expensive
9=Requires more rainfall
10=Labour intensive
11=Other, specify

4.4 For all types of inorganic fertilizer ever used in Table 4.3, please fill the following table

Inorganic fertilizer known **(copy from Table 4.3)**	Year first used	Reasons for using **Code B**	Main source of fertilizer **Code C**	Means of acquiring fertilizer **Code D**	Used fertilizer in 2013 LR* (0=N0; 1=Yes)	If No, why not (**Code A**, rank 3)	Before adopting had you observed its usage in the field? (0=N0; 1=Yes)	If Yes, where (**Codes E**, list 2)	If yes, was the plot located in your village (0=No; 1=Yes)

*In Tamale, 2011 and 2012

Code A
1=Cannot get fertilizer at all
2=Lack of cash to buy fertilizer
3=Cannot get credit
4=Lack of information on how to use
5=Poor prices
6=No market
7=Requires high skills
8=Fertilizers are expensive
9=Requires more rainfall
10=Labour intensive
11=Other, specify

Code B
1=Infertile soil
2=Established practice
3=High yields
4=……. … (*Please fill name*) recommended it to me
5=Other, specify

Code C
1=Research
2=Extension officer
3=Bought from local trader or agro-dealers
4=Provided by NGOs
5=Other (specify)…

Code D
1=Gift/free
2=Borrowed seed
3=Bought with cash
4=Payment in kind
5=Other, specify…..

Codes E
1=Parent
2=Child
3=Brother/sister
4=Grandparent
5=Grandchild
6=Nephew/Niece
7=Uncle/aunt
8=Cousin
9=Same family lineage
10=Mother/father in-law
11=Brother/sister in-law
12=Other relative
13=Fellow villager/Neighbor
14=Attend same church/mosqu
15=Professional/business colleague
16= Research station
17=. Demo/trial plot
18= Agricultural show

4.4 Please fill the following Table for all management practices the farmer knows and practices.

Which management practices are you aware of? **Code A**	When (year) did you first become aware of the practice?	From whom/where did you first hear about it?, rank up to three **Code B**	Year first used	Did you carry out the practice in 2013 LR*? How? (Go to Notes)			Will you carry out the practice in future? **(0=no; 1=yes)**	*If NO*, why not? (**Code D**, rank 3)
				(0=no; 1=yes)	If YES, give reasons (**Code C**, rank 3)	If NO, give reasons (**Code D**, rank 3)		

*In Tamale, 2011 and 2012

Code A
1=Lime application
2=Heaping or ridging
3=Crop residue use
4=Recommended spacing
5=Manure/compost application
6=Targeted manure application
7=Incorporation of urea/point placement of fertilizer
8=Crop rotation
9=Intercropping
10=Minimum tillage
11=Mulching
12=Relay intercropping
13=Catch cropping
14=Burning
15=Staggered planting
16=Use of drought-resistant crop varieties
17=Treatment of plant material
18=Intercropping
19= Sequential cropping
20= Other (Specify…)

Code B
1=Government extension
2=Farmer-based organisation
3=NGO
4=Research centre
5=On-farm trials/demos/field days
6=Seed/grain stockist
7=Another farmer/neighbor
8=Radio/newspaper/TV
9=Farmer magazine
10=Mobile phone updates
11=Drama/skit
12=Other, specify…..…

Code C
1=To increase soil fertility
2=To reduce acidity
3=To conserve soil moisture
4=To reduce soil erosion
5=To reduce weeds
6=To reduce pests
7=To cope with late rainfall
8=To curb soil crusting
8=To trigger dormancy of seeds
9=To create adequate depth for crops
10=Other, specify

Code D
1=Labour intensive
2=Lack of cash
3=No need to use it on any plot
4=The plots are very far
5=Organic resources are not available
6=Water is not available
7=Cannot get credit
8=Weather is erratic
9=Poor prices
10=No market
11=Requires high skills
12=It is not convenient
13=It is not appropriate for my case
14=Other, specify

Section 5: Social networks

Now I want to ask you questions about your interactions with a number of farmers, as well as key individuals (officers and organizations) who promote farming activities in this village or area.

5.1 How many people do you discuss with agricultural matters? ________________________

5.2 Out of these persons that you discuss agriculture with, have you exchanged with any of them information on soil fertility technologies and maize or vegetable production? (1=Yes, 0=No) ________________________

5.3 If Yes, how many? _________________________

5.4 Ego-based farmer social network (to discern strong ties).

Name a maximum of 3 persons with whom you frequently discuss agricultural matters	How is he/she related to you? (**Relationship codes**)	Which institution are they affiliated to? **Code A**	Do you belong to the same association? (fill in all that apply, **Code B**)	How often do you discuss agricultural matters with this person? **Code C**	How far is the person's residence/office from your homestead (km or min)?	What specific information regarding maize or vegetable production have you : **Code D**	
						Given to this person	Received from this person
1.							
2.							
3.							

Relationship codes
1=Parent;
2=Child;
3=Brother/sister; 4=Grandparent;
5=Grandchild; 6=Nephew/Niece;
7=Uncle/aunt;
8=Cousin;
9=Same family lineage;
10=Mother/father in-law;
11=Brother/sister in-law;
12=Other relative;
13=Fellow villager/Neighbor;
14=Attend same church/ mosque;
15=Professional/business colleague;
16=Other, specify…….

Code A
1=Government extension (MoFA)
2=Farmer-based organisation
3=NGO
4=Research centre
5=Government department
6=Seed/grain stockist
7=Another farmer/neighbor
8=Local government
9=Marketer
10=Media
11=Credit organisation
12=Other, specify…...…

Code B
0=No;
1=Farming group;
2=Self-help group;
3=Merry go round;
4=Savings and Credit;
5=Labour cooperative;
6=Other (Specify)………

Code C
1=Bi-annually
2=Annually
3=Quarterly
4=Monthly
5=Bi-weekly
6=Weekly
7=Daily
6-7=very often
4-5=often
1-3=occasionally

Code D
1=Information on modern maize seed varieties
2=Information on modern vegetable seed varieties
3=Information on maize marketing
4=Information on vegetable marketing
5=Information on inorganic fertilizer
6=Information on organic resources
7=Information on spacing requirements
8=Information on water harvesting techniques
9=Information on soil erosion control
10=Information on herbicide or pesticide use
11=Information on maize processing
12=Information on vegetable processing
13=Other, specify………

5.5 Further relationships, interactions and information exchange (weak ties). *[Fill in 1 for YES responses, 0 for NO responses &-99 for DON'T KNOW/NOT SURE]*

Farmers/External agent (X)	House hold ID	Do you know (X)	Since when (**Year**) have you known (X)?	Do you belong to the same religious congregation as (X)?	Do you belong to the same association as (X)? (fill in all that apply, **Code A**)	Have you ever discussed agricultural issues with (X)?	If NOT, would you contact (X) to discuss farming issues?	What specific information regarding maize or vegetable production have you : **Code B**	
								Given to (X)	Received from (X)
Farmers from the same village									
1.									
2.									
3.									
Farmers from the same cluster									
4.									
5.									
6.									
Village Administrators (7. Vice-chairman, 8. Chairman, 9. Village executive)									
7.									
8.									
9.									
External Agents*									
Agricultural Ext. Agent									
Research-									
NGO-									
Input dealer--									
Marketer--									
Government department									

Code A: 0=No; 1=Farming group; 2=Self-help group; 3=Merry go round; 4=Savings and Credit; 5= Labor cooperative; 6=Other (Specify)………**Code B**: 1=Information on modern maize seed varieties; 2= Information on modern vegetable seed varieties; 3=Information on maize marketing; 4= Information on vegetable marketing; 5=Information on inorganic fertilizer; 6=Information on organic resources; 7=Information on spacing requirements; 8=Information on water harvesting techniques; 9=Information on soil erosion control; 10=Information on herbicide or pesticide use; 11=Information on maize processing; 12=Information on vegetable processing; 13=Other, specify……… *Indicate the specific organization external the agent comes from.

SECTION 6: Assessment of channels used by farmers to receive ISFM information

This section assesses best-bet channels preferred by you, the farmer, along different stages of the value chain and attendant information seeking processes. [When assessing information seeking the interviewer should take care to ask the farmer whether the information search was an active, voluntarily process or one in which it was merely circumstantial i.e. passive; particularly with the community-based or interpersonal channels].

Stages of the value chain	ISFM information channels used **Code A**	Rank the different information channels on a likert scale***** of 1to 5 (with 1 being the least and 5 the highest)					Usefulness*	Frequency of contact with channel **Code B**	How much did you spend on channel (travel cost, sms charge, newspaper purchase etc)	
		Accessibility	Reliability	Informativeness	Comprehension	Credibility			Cash (Kshs/Ghc)	Time (hrs)
At the production stage (land preparation, planting, pest management, weeding, harvesting…..)										
At the marketing stage (prices for inputs and outputs, information on quality of input and outputs…..)										
At the processing stage (on-farm and/or industrial; information leading to value-addition…..)										

*1- Very poor; 2- Not good; 3- Satisfactory; 4- Good; 5- Excellent **Weighting system: ≤0.2 -Not useful at all; >0.2≤0.4- A little useful; >0.4≤ 0.6- Somewhat useful; >0.6≤0.8- Useful; >0.8≤1- Very useful **Code A**: 1=Farmer Field Days; 2=Workshops/Seminars; 3=Farmer Field Schools; 4=On-farm demonstrations; 5=Farm-to-farm visits; 6=Public gatherings (barazas); 7=Songs/Poems/Skits; 8=Neighbours/Friends/Relatives; 9=Extension visit; 10=Radio; 11=Television; 12=Newspapers; 13= Farmer Magazines; 14=Billboards/Posters/Brochures; 15=Books; 16=Mobile phones; 17=Internet; 18=DVD/CD players; 19=Others specify (_____)

Code B: **0** for no contact, **1** for once a year, **2** for two times a year for two or three times a year, **4** for four or five times a year, **12** for once a month, **30** for two or three times a month, **52** for once a week, **130** for two or three times a week and **365** for information contacts once a day.

Section 7: Membership of farmer organizations/clubs

Is any of your household members a member of an association, group, or club (**0**=No; **1**=Yes)	If no, give reasons (**Codes A,** rank 3)	If Yes, what's the name of Association, Coop , Group, or club (List all)	Who is a member **Code B**	Type of membership **Codes C**	Association or club functions **Codes D, rank 2**	**Year** joined	Current Entry fee, if any **(Kshs/Ghc)**	Subscription fee, if any **(Kshs/Ghc)**	Frequency of subscriptions **Codes E**	Frequency of meetings (**Codes E**)	Number of meetings member attended in last 12 months	Total number of members	Has your group been visited by extension officer in the last 2 years? (0=No; 1=Yes)

Code A
1=No need to join one
2=No such groups exist in the area
3=Cannot afford subscription fee
4=Does not have time for group meetings
5=No faith in leadership of existing groups
6=Other, specify ……………………….
………………………………………….

Code B
1=Household head
2=Spouse
3=Son/daughter
4=Parent
5=Son/daughter in-law
6=Grand child
7=Other relative
9=Other, specify……

Codes C
1=Ordinary member
2=Executive committee member
3=Other committee member
4=Patron
5=Other, specify……………

Code D
1=Crop/livestock marketing
2=Input access/marketing
3=Seed production
4=Farmer research group
5=Savings and credit
6=Welfare/funeral club
7=Tree planting and nurseries
8=Soil & water conservation
9=Input credit
10=Local administration
11=Labor
12=Other, specify………

Code E
1=Weekly
2=Bi-weekly
3=Monthly
4=Every 3 Months
5=Every 4 Months
6=Every 6 months
7=Yearly
8=Not regular
9=Other, specify……………
………………………

SECTION 8: Information/Knowledge centers

Type of Information Center		Frequency of use by farmer? 0=Never;1=Occasionally; 2=Moderately frequent; 3=Very frequent	Distance to the information center (km)
ID	**Name**		
1	Rural Knowledge Centers		
2	Cyber Cafes		
3	Market Information Centers		
4	Libraries		

SECTION 9: Access to credit

9.1 If you needed money, could you borrow it at present? 0=No; 1=Yes

9.2 If Yes, from which sources could you borrow the money?

Credit source			Could you borrow? (0=No; 1=Yes)
SACCO (Registered)			
Bank			
Micro Finance Institution			
Credit/Farmer/self-help group			
Shopkeeper/trader in the village			
Shopkeeper/trader outside the village			
Other persons (Let the farmer mention these)			
Name	Relationship (**Relationship Codes**)	Residence (**1**=In this village; **2**=Outside this village)	
1.			
2.			
3.			
4.			

Relationship Codes **1**=Parent; **2**=Child; **3**=Brother/sister; **4**=Grandparent; **5**=Grandchild; **6**=Nephew/Niece; **7**=Uncle/aunt; **8**=Cousin; **9**=Same family lineage; **10**=Mother/father in-law; **11**=Brother/sister in-law;**12**=Other relative; **13=**Fellow villager/Neighbor; **14**=Attend same church/ mosque; **15=**Professional/business colleague; **16**=Other, specify…….

This is the end of the survey. Thank you very much for your participation!

Thank you very much for your patience!

Notes:

Interviewer, please note any other unique adaption practices carried out by the farmer on his or her fields (particularly those that can be seen by observation e.g. local techniques for dealing with insect pests, selection of planting materials, adaptation of farm tools). Briefly describe how the farmer carries out these practices and others mentioned above.

Soil data

Interview/Household ID: [_ _ _] *(to be entered only AFTER completion of survey)*

	House	Field ID			Field ID		
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Waypoint name							
Latitude							
Longitude							
Notes on soil sample/ vegetation cover							
Soil sample method, 1=pipe, 2=shovel							
Any other remarks e.g. soil sample depth if different than 20cm							

Number of field corners: ___________________________