SMALLHOLDER FARMER GRAIN-LEGUME INTEGRATION IN CENTRAL MALAWI

By

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ABSTRACT

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Over the last two decades, researchers have heavily promoted grain-legume technologies as a soil amelioration strategy for smallholder farmers in Malawi. Although farmers have been involved in the development of and have expressed great interest in these technologies, their uptake of them has been minimal. Understanding this disconnect is important for both researchers and farmers because Malawian soils are not conducive to the current low-input continuous maize monocropping that dominates the Malawian landscape, ultimately resulting in marginal yields. Therefore, we used various methods and components of participatory action research to determine the drivers and implications of farmers' (n=363) integration and management of grain-legume technologies in their maize-based cropping-systems. We explored farmers' perceptions associated with the promoted technologies' benefits as well as their on-farm soil fertility to understand farmers' reasoning for their grain-legume integration and management choices when collaborating with researchers. Additionally, we investigated the implications of these choices on subsequent maize production. Two survey instruments were used to determine farmers' perceptions of grain-legume technologies and to monitor farmers' cropping-system management in collaborative research trials (n=1186) over four years (2013-2016). Soil samples (n=1729) were collected and analyzed from both farmers' traditional maize plots and their collaborative trials to determine the soil properties associated with farmers' perceptions of soil fertility and cropping-system allocation choices. After four years of farmers' on-farm experimentation with grain-legume technologies, we conducted a field experiment on thirty collaborative research trials to determine the effects of farmers' current and historical management of grain-legume technologies on subsequent maize production.

We found that farmers' overall motivation for integrating grain-legumes into their maize-based cropping-systems was for soil amelioration. Yet, while farmers continue to indicate that they prefer grain-legume technologies over their continuous maize monoculture, in this study they perceived them to be

inferior in terms of meeting farmers' immediate needs, like food security. This perception does not reflect scientific evidence showing that grain-legume integration in maize-based systems maintains and often increases maize yield, yet it was a major contributing factor in farmers' grain-legume integration decisions. Moreover, farmers' perceptions of soil fertility were associated with scientific indicators of soil fertility and heavily contributed to farmers' decisions and subsequent maize production. Foremost, farmers allocated their collaborative research trials to soils of lower fertility than their traditional maize plots. Within collaborative research trials, farmers preferentially allocated their soil amendment resources to continuous maize plots, which were allocated to soils of higher fertility than the grain-legume technologies. Farmers' preferential allocation was a key contributing factor in subsequent maize crop response where plots with a history of continuous maize intense cropping had a greater positive effect on subsequent maize crop production than plots with a history of legume intense cropping-systems.

This dissertation revealed some of the synergies as well as disconnects that exist between researchers and farmers associated with grain-legume integration. These findings have implications for technology uptake and collaborative on-farm research. We suggest that both farmers' grain-legume integration and their preferential allocation of maize-intense systems to higher fertility soils are two soil amelioration strategies used by central Malawian smallholder famers. Although, farmers' motivations for cultivating grain-legume technologies are aligned with that of researchers', e.g. integration as a soil amelioration strategy, farmers' incomplete understanding of associated management and livelihood benefits suppresses the potential associated benefits, like soil amelioration and increased food security. If not further understood, this disconnect may continue to limit farmers' uptake of these promising technologies and has the potential to introduce bias into future collaborative research efforts.

Therefore, we suggest that future efforts that promote agricultural technologies must intensify their farmer education to include the underlying agroecological principles associated with the promoted technologies. Not only does this have the potential to increase the success of the developed technology, it may ultimately provide farmers with the knowledge necessary to increase their overall cropping-system productivity based on sound scientific principles, without the assistance of researchers.

This dissertation is dedicated to the many farmers who, without hesitation, trust their lives with the soil they walk on. May they forever be blessed with showers from heaven, bountiful harvests and continued laughter.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

0	no amendment
BN	bean
BN1	sole cropped bean
BS	% base saturation
C	carbon
C:N	carbon to nitrogen ratio
Ca	calcium
CEC	cation exchange capacity
CP	cowpea
CP1	sole cropped cowpea
EPA	Extension Planning Area
EXP	experimental
GLI	grain-legume integration
GN	groundnut
GN1	sole cropped groundnut
GNSOY	groundnut intercropped with soyabean
GPS	global positioning satellite
H	high
INORG	inorganic
INTEG	integrated

INTER	intercropped
KCL	potassium chloride
L	low
L0M	sole maize sub-system
L1	sole legume sub-system
L1M	mixed maize intercropped with one legume sub-system
L2	mixed legume intercropped with two or more legumes sub-system
L2M	mixed maize intercropped with two or more legumes sub-system
LEG	legume
LI	legume intense cropping-system history
Mg	Magnesium
MI	maize intense cropping-system history
Mn	Manganese
MZ	maize
MZ1	sole maize technology
MZ2	maize crop residue treatment at the rate of 2 Mg ha^{-1}
MZ4	maize crop residue treatment at the rate of 4 Mg ha^{-1}
MZBN	maize intercropped with bean
MZCP	maize intercropped with cowpea
MZGN	maize intercropped with groundnut
MZGNSOY	maize intercropped with groundnut and soyabean
MZPP	maize intercropped with pigeonpea

MZSOY	maize intercropped with soyabean
N	nitrogen
Na	sodium
NH_4^+	ammonium
NO	no amendment
NO_3^-	nitrate
ORG	organic
P	phosphorous
PAR	participatory action research
PP	pigeonpea
PP1	sole cropped pigeonpea
PP2	pigeonpea litter treatment at the rate of 2 tonnes ha^{-1}
PP4	pigeonpea litter treatment at the rate of 4 tonnes ha^{-1}
PPCP	pigeonpea intercropped with cowpea
PPGN	pigeonpea intercropped with groundnut
PPSOY	pigeonpea intercropped with soyabean
RCBD	randomized complete block design
SOLE	sole cropped system
SOM	soil organic matter
SOY	soyabean
SOY1	sole cropped soyabean
SSA	sub-Saharan Africa

TOC	total organic carbon
TN	total nitrogen
TON	total organic nitrogen
TRAD	traditional
TRADexp	traditional experimental plot

CHAPTER ONE

INTRODUCTION

Since the mid-1960s, agricultural research and development efforts in sub-Saharan Africa (SSA) have resulted in a variety of agricultural technologies designed to improve the area's land productivity. Many of the earlier efforts either focused on enhancing the productivity of commercial agriculture including cash crops such as tobacco, cotton and tea, or was based on researcher identified technologies that were thought to be superior to smallholder practices (Vanlauwe et al., 2017). As such, these technologies were designed to replace existing smallholder systems and were tested exclusively on research stations located off-farm under edaphic and management conditions not fully representative of the smallholder context (Vanlauwe et al., 2017; Ngwira et al., 2014; Kwesiga et al. 2003; Snapp et al, 2002b). Likewise, these technologies often reflected the high input, mechanized and irrigated cropping-systems of the Global North (Franke et al., 2014; Jayne et al., 2014; Mulwafu, 2011; Sirrine, 2010; Goldman, 1995). Unlike the conditions found on research stations and in the Global North, smallholder farmers' cropping-systems are largely rain-fed, low input, extremely heterogeneous in nature, dominated by unfertilized crops and manual labor (Goldman, 1995). When researcher-developed technologies were placed on smallholder farms, cropping-system productivity was lower than that achieved on research stations or was not adopted by farmers (Mponela et al., 2016; Meijer et al., 2015; Chikowo et al., 2014; Harou et al., 2014; Ngwira et al., 2014; Tittonell and Giller, 2013; Mulwafu, 2011; Green, 2007). Farmers' non-adoption of these technologies suggests that researcher and farmer priorities as well as understandings were not aligned. Therefore, other than their adaptive strategies, farmers were left with few available options for addressing their needs (Gowing and Palmer, 2008).

When farmers are exposed to agricultural technologies that do not fit their realities, they do not simply reject them, rather they often create adapted 'hybrid' technologies, which include a combination of components from both their own experiences as well as those of external technologies, which they perceive to more favorably address their particular farming-system challenges (Roling, 2009; Gowing and Palmer, 2008; German et al., 2006). These adapted technologies account for and reflect farmers' preferences, perceptions, resource bases, farming-system needs and overall livelihood strategies (Falconnier et al., 2016; Franke et al., 2014; Giller et al., 2009). Farmers' adaptations, perceptions and preferences, of both the researcher developed and their own technologies provide valuable insights for understanding and adjusting technologies to be aligned with farmers' needs (Kristjanson et al., 2009; German, 2006). In addition to understanding the on-farm context, these insights are often used in agricultural research and development to explore the farmers' interest in and potential uptake of a proposed technology as well as exposing any underlying knowledge gaps between researchers and farmers (Falconnier et al., 2016; Meijer et al., 2015; Bezner-Kerr et al., 2007; Snapp and Silim, 2002). To explore these dynamic variables, various qualitative techniques such as focus group discussions, key informant interviews and face-to-face qualitative interviews are often used (Greenwood et al., 1993).

A widely recognized and successful approach used to abate these challenges is participatory action research (PAR). The collaborative, iterative and reflective nature of PAR facilitates impactful outcomes across the various scales of actors involved in smallholder farming, specifically at the community and farm level (Anderson et al., 2016; Falconnier et al., 2016; Vanlauwe et al., 2015; World Bank, 2006). These results are especially important for agricultural research and development because, unlike the traditional quantitative modes of inquiry that are developed on research stations using a set of research-determined hypotheses, PAR is conducted in the on-farm context and actively involves the on-farm decision makers – the farmers (Chandler and Torbet, 2003; Mc Cown, 2001; Carberry, 2001; Marshall, 2001). This co-learning approach encourages open dialect between researchers and farmers. Ultimately, these collaborative on-farm efforts can lead to positive changes in smallholder cropping-systems by revealing farmer-appropriate technologies that are both scientifically grounded and that encompass the many realities smallholder farming-systems (Kristjanson et al., 2009; Roling, 2009; Marshall, 2001). It is for these reasons that after nearly thirty years of limited farmer adoption of developed technologies and stagnant or declining land productivity in Malawi, many researchers, donors and institutions have actively begun to include various PAR methods in agricultural research and development (Anderson et al., 2016; World Bank, 2006).

Although this recent change has facilitated a deeper understanding of the on-farm reality, the effects of farmers' and researchers' incorporation of these insights takes a considerable amount of time. As result, land productivity has only marginally improved and farmers' adoption of new technologies remains minimal (Mponela, 2016; Kolawole, 2013; Green, 2007; Snapp et al., 2003; Harrigan, 2003). In the past, proposed technologies were primarily designed to address researcher-perceived on-farm biological and yield constraints. However, recent PAR activities revealed that the heterogeneity of farmers' inherent soil properties, cropping-system management strategies and access to information, calls for recommendations that are based on farmers' varied circumstances (Franke et al., 2014; Jayne et al., 2014; Kolawole, 2013; Ellis et al., 2003; Harrigan, 2003; Snapp et al., 2003; Snapp et al., 2002b; Goldman, 1995). This is a challenge because farmers' cropping-system choices and management strategies are often influenced by a complex set of attributes that go beyond the on-farm biological and yield constraints. Often farmers must consider livelihood attributes like food security, crop marketability, nutritional diversity, cropping-system labor requirements and harvested grain storability when making their decisions (Snapp et al., 2017; Smith et al., 2016; Fisher and Snapp, 2014; Franke et al., 2014; Sirrine et al., 2010b; Snapp et al., 2002a; Snapp et al., 2002b). Ultimately, these biological and yield constraints cannot be properly addressed without considering the diverse realities of farmers. This means that in addition to soil fertility, newly developed technologies must also include farmers' cropping-system management strategies that are understood by the researcher based on farmers' knowledge.

Soil provides many of the essential nutrients to maintain crop yield and land productivity (Roxburgh and Rodriguez, 2016; Carberry et al., 2013; Snapp et al., 1998). In cropping-systems like that of SSA where the soils are highly weathered, deprived of key nutrients and extremely heterogeneous in nature, maintaining adequate soil productivity has become an endemic challenge (Below, 2001; Snapp, 1998). This is a particular challenge in land limited, maize-dominated systems, like that of Malawi, where soils are mainly aged Alfisols, Oxisols and Ultisols comprised of acidic loamy sands, low in organic C and have been depleted of the key nutrients required for maize production (Snapp, 1998). These challenges are further complicated by the varied cropping-system management strategies of smallholder farmers, especially their cultivation of continuous monocrop maize without the return of adequate nutrients – further degrading the soil (Guerena et al., 2016; Laird and Chang, 2013).

In addition to soil fertility, farmers' perceptions of their realities have a profound effect on both their cropping-system management decisions and their collaboration with researchers. The extent to which technologies are appropriate to the on-farm context contributes to farmers' cropping-system choices and therefore understanding farmers' perceptions at the onset of technology development is of the upmost importance (Anderson et al., 2016; Vanek and Drinkwater, 2016; Falconnier et al., 2016; Vanlauwe et al., 2015; Snapp et al., 2003). Farmers are known to preferentially allocate available cropping-system resources, such as available land, labor and inputs, based on their perceptions of soil fertility (Tittonell et al., 2008; Tittonell et al., 2007; Mowo et al., 2006). These decisions often lead to management gradients that result in spatial soil fertility and variable production (Tittonel et al., 2013; Tittonel et al., 2005). If not fully understood, soil fertility gradients make relevant management recommendations difficult and can be detrimental to agricultural development efforts. Often these gradients introduce confounding factors into the research that were not previously accounted for during the research design – potentially leading to results that may be detrimental or not applicable to the on-farm context (Brooks, 2014; Roling, 2009).

Finally, there challenges are further complicated because the dissemination of important soil fertility and cropping-system knowledge is difficult in many rural areas in SSA because of various logistical and social challenges (Mapila et al., 2016; Snapp et al., 2003). Specifically, in Malawi agricultural interventions and recommended cropping-system management strategies are primarily disseminated by governmental agricultural extension networks, which do not extend to many of the farmers. Therefore, in the absence of adequate information, farmers often continue to cultivate systems using strategies that further degrade their soils – resulting in low crop productivity (Kassie et al., 2015; Hockett et al., 2014). Subsequently, farmers' uptake of new agricultural technologies is often minimal and researchers' understanding of farmers' technology adaptation becomes even more important.

Farmers' adapted "hybrid" technologies reflect the misaligned perceptions between farmers and researchers, which are in-line with their own understanding of the technology. For example, if farmers' understanding of the technology's management is not aligned with researchers', farmers will adjust the technology to reflect their agroecological knowledge base. This adjustment can result in improper management of the new technology so that the technology's benefits are not realized, and the technology may be abandoned do to the misaligned understandings between farmers and researchers. Rather than as a tool to understand the reasons for non-adoption, in the past, farmers' adoption of researcher-designed technologies has been explored in terms of farmer groups based on livelihood attributes such as socio-economic classification or farmer resource endowment (Franke et al., 2014; Chikowo et al., 2014; Kamanga et al., 2010). As a result, researchers have identified farmers' unilateral *adoption* of technologies as an indication of research success – integrating researcher-designed technologies in the prescriptive manner in which they were designed. This overlooks farmers' *adaptation* of technologies to fit their realities (German, 2006). However, the use of PAR can mitigate these challenges; by introducing technologies that are more relevant to the on-farm conditions. This ultimately closes the knowledge gap between researchers and farmers because the technologies are developed and tested with farmers in their environments (Cobeels et al., 2014; Kiptot et al. 2007; Bolliger et al., 2006). The effects of PAR have not gone unnoticed by researchers or donors and in addition to demanding an increased use of PAR there has also been a call for researchers' understanding of farmers' adaptations of the developed technologies. However, in a heterogeneous environment like that of SSA, understanding the on-farm context and farmers' motivations for technology adaptation using PAR is time consuming and are not, as of yet, fully understood (Giller et al., 2010; Snapp, 2002). In response, researchers have begun to develop and disseminate several potential farmer-appropriate technologies using PAR (Waldman et al., 2017; Mungai et al., 2016; Franke et al., 2014; Mhango et al., 2013; Snapp et al., 2010; Bezner-Kerr et al., 2007; Marshall, 2001).

Over the last two decades, in Malawi, researchers have been actively, with farmers, exploring farmers' potential uptake of perennial legume agroforestry technologies using PAR. These technologies were initially introduced in the late 1990s as a management tool to increase cropping-system soil fertility, biodiversity and productivity in smallholder farming-systems of SSA (Vanlauwe et al., 2017). Although these technologies were largely successful on research stations and farmers expressed interest in their benefits, they were not widely preferred or adopted by smallholder farmers (Sirrine et al., 2010b; Mhango et al., 2012; Snapp et al., 1998). In response, researchers began to employ more intensive quantitative and qualitative methods to explore the reasons as to why farmers expressed interest did not reflect their current cropping systems or technology adoption. The results of these efforts indicated that farmers seemed to be prioritizing the potential short-term benefits of their maize cropping-systems like food security and can increase nutritional diversity and supplemental household income over the long-term benefits of increased soil fertility (Franke et al., 2014; Mhango et al., 2013; Bezner-Kerr et al., 2007; Snapp et al., 2002b). As a result, researchers began to explore more farmer applicable technologies like that of grain-legume integration (GLI) technologies, which included novel legume – legume intercropping and semi-perennial varieties, rather than the previously promoted non-grain-legume technologies (Kamanga et al., 2014; Snapp and Silim, 2002). Like non-grain-legume technologies, GLI technologies can also increase system biodiversity. On low productivity soils, legumes are known to occupy specific cropping-system niches that are not suitable for maize. For example, when additively intercropped or included in rotation grain-legumes, unlike non-grain-legume technologies, GLI technologies have the ability to increase both short and long-term cropping system sustainability while maintaining maize yield (Falconnier et al., 2016; Franke et al., 2014; Smith et al., 2016; Mhango et al., 2013; Snapp et al., 2010; Ogoke et al., 2009; Ojiem et al., 2007; Snapp et al., 2003; Snapp et al., 2002b). In several studies, farmers have indicated that they prefer GLI technologies over their traditional maize dominated systems (Siddique et al., 2012; Snapp et al., 2010; Snapp et al., 2002a; Snapp and Silim, 2002; Kanyama-Phiri et al., 1998). However, it has yet to be understood what effect farmers' stated preferences or their perceptions of both GLI technologies and their soil fertility will have on their integration of GLI technologies into their maize-based systems.

It is difficult to understand farmers' realities without the use of PAR for it is well known for its ability to explore the on-farm context; however, it is a time consuming and costly process with many necessary and often complex components. Regardless of its shortcomings, action research holds promise for the development and dissemination of farmer applicable technologies that can alleviate many of the challenges faced by smallholder farmers. Often, PAR is used to provide potential solutions rather than effective solutions; this leaves efforts unfinished and may consequently divide the research and the smallholder farmer community (Kipot et al., 2007). Ultimately, it is the alignment of the farmers' and researchers' perceptions associated with the on-farm context that determines the success of agricultural development (Falconnier et al., 2016; Franke et al., 2014; Giller et al., 2009; Roling, 2009; German et al., 2006; Snapp et al., 2003; Snapp and Silim, 2002). Although participatory action research has been used to understand the applicability and potential uptake of recently developed agricultural technologies, (Waldman et al., 2016; Mungai et al., 2016; Franke et al., 2014; Mhango et al., 2013; Snapp et al., 2010; Bezner-Kerr et al., 2007; Marshall, 2001), farmers' integration, resulting perceptions and its effects on maize productivity remains unknown.

Therefore, to the overall objective of this dissertation was to determine the drivers and implications of farmers' on-farm integration and management of grain-legume technologies in their maize-based cropping-systems. The specific objectives were to:

1) determine how and why farmers are integrating grain-legume technologies in their maize-based cropping systems of central Malawi;
2) understand farmers' perceptions of soil fertility and how, in collaboration with researchers, it affects their integration of grain-legume technologies into maize systems;
3) investigate the role of farmers' historical and current cropping system management choices of grain-legume technologies on subsequent maize crop production.

We found that ultimately there continues to be a disconnect between farmers' and researchers' perceptions of available GLI technologies, farmers' perceptions of soil fertility drive their cropping-system management decisions. However, farmers have yet to realize the technology's potential positive benefits like increased soil fertility due to the misalignment between farmers' and researchers' understanding of their management. Although farmers' motivations for cultivating GLI technologies are aligned with that of researchers e.g. integration for increased soil fertility, we suggest that future efforts in the promotion of GLI technologies must intensify their farmer education efforts beyond that of demonstration plots and more towards the underlying agroecological principles associated with the technologies. Not only does this have the potential to increase the success of the developed technology, it may ultimately provide farmers with the knowledge necessary to increase their overall cropping-system productivity based on sound scientific principles, without the assistance of researchers.

1.1 Dissertation Outline:

Chapter two describes farmer integration of grain-legume technologies over four years of farmer experimentation and reflects on this information to understand the effects on farmer integration of GLI technologies as a result of farmers' perceptions of them. Chapter three further explores farmers' perceptions of soil fertility and their effects on farmers' integration and management of grain-legume technologies in collaboration with researchers. Chapter four examines the effects of farmers' historical and current cropping system management strategies of grain-legume technologies on subsequent maize crop production. Finally, chapter five reflects on and synchronizes the results of the study.

CHAPTER TWO

SMALLHOLDER FARMER PERCEPTIONS ASSOCIATED WITH GRAIN-LEGUME INTEGRATION IN CENTRAL MALAWI

Problem Statement:

Over the last two decades, researchers in Malawi has been actively including the smallholder farmer in the development of soil amelioration technologies, yet farmer adoption of these promising technologies remains limited and there continues to be a gap in technology production potential and on-farm production. On technology that farmers continue to express great interest in is grain-legume integration (GLI) technologies. These technologies were designed by researchers and further co-evaluated and refined with farmers in Malawi over the last two decades. However, despite their expressed interest, farmers' adoption of these technologies is not wide-spread and researchers' understanding of farmers' integration of them remains limited. Therefore, in this study we used PAR to investigate farmers' integration of GLI technologies with particular interest in understanding farmers' reasoning for their integration. We used various methods of PAR and active on-farm farmer experimentation to examine the effects of farmers' perception s of GLI technologies on their cropping-system choices. We found that although farmers have indicated that they prefer GLI technologies to their traditional maize-based systems, their integration of them remains limited because farmers perceive them to be inferior to their maize systems, specifically in terms of food security. This perception is not in-line with scientific evidence that shows that, with proper management, GLI technologies can increase maize yield. This disconnect is detrimental to the success of this promising technology because farmers are not able to realize the technology's potential benefits due to farmers' incomplete understanding of the technology's management and benefits. Therefore, it is imperative that future research efforts place particular focus on developing strategies for communicating not only the proper management of proposed technologies but also include agroecological theory that explains the technology's benefits beyond that of soil fertility.

2.1 Introduction:

Over the five decades of agricultural research and development, various agricultural technologies have been designed to improve land productivity and the livelihoods of smallholder farmers in Malawi, however there continues to be a gap between newly promoted technology potential and realized on-farm production (Green, 2007; Snapp et al., 2003). Recently, researchers have begun to explore farmers' constraints and preferences associated with technology non-adoption using various participatory action research (PAR) methods (Mponela, 2016; Kolawole, 2013; Harrigan, 2003). These studies have repeatedly shown that many of the developed technologies have the ability to mitigate some of the cropping-system and livelihood challenges faced by smallholder farmers, specifically technologies that include grain-legumes (Siddique et al., 2012; Snapp et al., 2010; Snapp et al., 2002a; Snapp and Silim, 2002; Kanyama-Phiri et al., 1998). Farmers indicate that they value GLI technologies for their soil amelioration properties and their productivity on soils that are not suitable for maize (Franke et al., 2014; Mhango et al., 2013; Bezner-Kerr et al., 2007; Ojiem et al., 2007; Snapp et al., 2002b). As a result, researchers in Malawi have been collaborating with farmers to further develop these promising grain-legume integration (GLI) technologies, yet despite these efforts farmers' uptake remains limited (Snapp et al., 2002b).

A recent study in Malawi suggests that farmers' non-adoption of GLI technologies may be associated with farmers' knowledge and perceptions of grain-legume associated livelihood attributes like food security and labor. The authors suggest that this is in part due to the persistent disconnect between farmers stated preferences for GLI technologies over their traditional maize and their actual integration (Waldman et al., 2016). That is to say that although farmers often indicate to researchers that they prefer GLI technologies over their traditional maize technologies, farmers do not integrate them in their cropping-systems. The exact reasons for this conflicting outcome are unknown but it has been suggested that either farmers are not fully aware of their potential benefits or they perceive their traditional maize systems to be superior at meeting their needs, despite research findings that indicate otherwise (Waldman et al., 2016). For example, studies have repeatedly shown that many of the GLI technologies meet farmers needs by maintaining or increasing maize yields, spreading risk through crop diversification and increasing access to a more nutritionally diverse set of staple crops, yet researchers continue to find that these same concerns remain as the primary obstacles to farmers' integration of GLI technologies (Droppelmann et al., 2017; Falconnier et al., 2016; Franke et al., 2014; Mhango et al., 2013; Snapp et al., 2010; Ogoke et al., 2009; Orr, 2003; Snapp et al., 2003; Snapp et al., 2002b). Moreover, in many of the *ex-ante* studies farmers indicated that they are also concerned about the additional labor requirements associated with the integration of grain-legumes. Yet, there is strong agroecological evidence that legumes reduce cropping-system labor requirements by suppressing weeds (Snapp et al., 2002a; 2002b).

To the best of our knowledge there is limited empirical evidence associated with farmers' perceptions of GLI technologies and their effect on farmers' integration of GLI technologies, specifically in Malawi. Therefore, in this study we used farmers' active on-farm experimentation to understand farmers' 1) actual integration of and 2) preferences as well as 3) perceptions of GLI technologies after four years of active on-farm experimentation. We found that ultimately farmers' lack pertinent information associated with the management and benefits of GLI technologies. This knowledge gap is negatively affecting farmers' cropping system choices and their integration of grain-legumes and calls for efforts to close the gap. This not only has the potential to increase farmers' adoption of promoted GLI technologies, it ultimately has the potential to increase farmers' over-all cropping-system productivity because farmers' management decisions will be informed by sound agroecological principles.

2.2 Methods and Materials:

This observational study was part of a larger four-year experiment (Africa RISING – Malawi). To investigate farmers' integration, perceptions and preferences of GLI technologies we used a variety of qualitative and quantitative methods. Data was collected at two-time points: 1) 2014 post-harvest and 2) 2016 post-harvest. The methods used were: 1) active farmer on-farm experimentation with GLI technologies, 2) focus group discussions at the village level, 3) key-informant interviews with lead farmers and local extension agents, 4) researcher participant observation of on-farm cultivation and 5) a survey instrument (further described in section 2.3.1 of this chapter). Both in-field measurements and farmer recall data was collected (explained further in this section). To ensure that the qualitative methods reflected the on-farm context, key informant interviews, on-farm researcher participation and focus group discussions were used to define farmers' livelihood attributes, refine the survey instruments as well as to further enrich and explain research results

2.2.1 Site Selection

Project sites were selected in early 2012 and project implementation began during the 2012-2013 growing season. The two central districts south of Malawi's capital city, Lilongwe, were selected for the project (Dedza and Ntcheu). Two Extension Planning Areas (EPA) were randomly selected within each district (Figure 2.1.). Each EPA was naturally separated by rivers or roads into east and west sections (1-6 villages $section^{-1}$ EPA^{-1} – a total of eight sections) (Mungai et al., 2016; Hockett et al, 2014). The EPAs represent four sub-humid agroecozones along a production potential gradient (marginal, moderate and high) based on the following parameters: 1) market access, 2) altitude, 3) dominant soil texture, 4) daily evapotranspiration rate and 5) cumulative annual rainfall. The sites are of unimodal precipitation with altitudes ranging 546-1244 meters above sea level, annual precipitation ranging from 800 to 1006 mm $year^{-1}$ (Table 2.1).

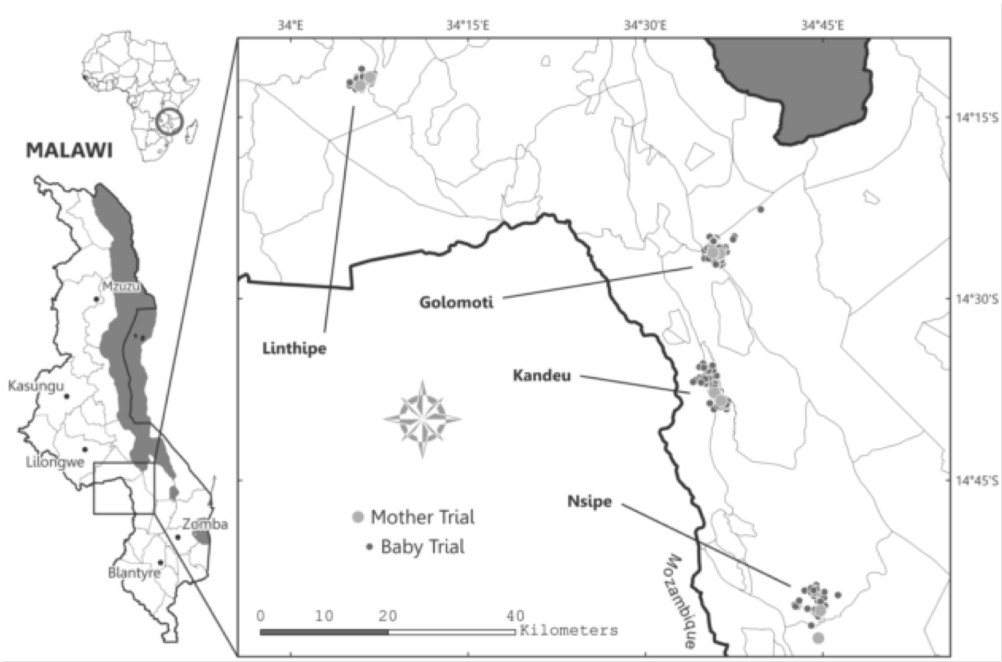

Figure 2.1 Map of Africa RISING-MALAWI Mother and Baby trial locations in four agricultural Extension Planning Areas
(*Map courtesy of Brad Peter, Michigan State University. 2017. Department of Geography*)

Table 2.1 Description of EPA production potential attributes, original and participating farmers counts, experimental and farmer-initiated plot counts, the area of studied landholding, and the total landholding by plot type and farmers per District and EPAs within Districts †(Mungai et al., 2016) ‡(Hockett et al., 2014).

District	Dedza		Ntcheu	
EPA	Linthipe	Golomoti	Kandeu	Nsipe
Production Potential	high	marginal	moderate	moderate
Distance from market (km from EPA center)†	5	1	2	9
Elevation (meters above sea level)†	1238	555	904	868
Dominant soil texture (USDA classification)‡	Loamy Clay	Loamy Sand	Sandy Clay	Sandy Clay
Daily evapotranspiration rate (mm)†	595	960	800	810
Annual rainfall (mm)‡	1006	891	800	811
Original farmers (n)	104	76	91	95
Participating farmers (n)	59	65	83	81
EXP plots (n)	310	224	316	336
TRADexp plots over 3 years (n)	747	486	495	866
Total area landholding (ha)	93.9	40.0	66.3	78.2
Total area EXP plots (ha)	16.5	7.4	12.2	5.5
Total area TRADexp plots (ha)	40.7	12.1	21.1	18.9
Mean area landholding farmer $^{-1}$ (ha)	1.19	0.77	1.25	1.10
Mean area EXP trial^{-1} (ha)	0.19	0.11	0.15	0.07
Mean area TRADexp plot $^{-1}$ (ha)	0.21	0.11	0.14	0.18

2.2.2 Mother/Baby Trial Design

The Mother – Baby PAR trial design was used (Snapp, 2002) to facilitate farmer accessible demonstration trials as well as for farmer evaluation of the GLI technologies of interest (described later in this section). Beginning in mid-2012, researchers and local extension agents identified lead farmers to participate as the Mother trial farmers in each EPA. Table 2.2 describes the twelve GLI technologies demonstrated on each Mother trials. These demonstration plots were located in a central area of each village on a lead farmer's field. The recommended management strategies of each technology were demonstrated on Mother trials at the beginning of every growing season. Farmers were asked to integrate the demonstrated technologies in their own on-farm trials as they found applicable (Baby trials). The Baby trials were then monitored using the various methods described in sections throughout this chapter.

Table 2.2 GLI technologies and applied soil amendment application demonstrated on Mother trials classified by sub-systems within systems. NPK fertilizer compound (23:21:0) and manure was locally sourced and varied by variety (cattle, pig, goat, sheep and chicken).

System	Sub-System	Technology	Soil Amendment
SOLE	L0M	MZ1	None
SOLE	L0M	MZ1	NPK 100 kg ha^{-1} + UREA 100 kg ha^{-1}
SOLE	L0M	MZ1	Manure 3-5 Mg ha^{-1} + UREA 100 kg ha^{-1} + NPK 100 kg ha^{-1}
SOLE	L1	PP1	NPK 50 kg ha^{-1}
SOLE	L1	BN1	NPK 50 kg ha^{-1}
SOLE	L1	CP1	NPK 50 kg ha^{-1}
SOLE	L1	GN1	NPK 50 kg ha^{-1}
SOLE	L1	SOY1	NPK 50 kg ha^{-1}
INTER	L2	PPCP	NPK 50 kg ha^{-1}
INTER	L2	PPGN	NPK 50 kg ha^{-1}
INTER	L2	PPSOY	NPK 50 kg ha^{-1}
INTER	L1M	MZPP	NPK 50 kg ha^{-1}
INTER	L1M	MZBN	NPK 100 kg ha^{-1} + UREA 100 kg ha^{-1}

The demonstrated GLI technologies were developed on-farm in Malawi over the past two decades and expanded on the previously identified grain-legume species. These technologies were designed to address crop yield and environmental protection with particular interest in farmers' livelihood opportunities and challenges (Mhango et al., 2013; Snapp et al., 2010; Bezner Kerr et al., 2007; Snapp and Silim, 2002; Snapp et al., 2002b; Marshall, 2001). Improved seed varieties of four commonly grown annual grain-legume species were introduced: bean (*Phaseolus vulgaris)* (BN), cowpea (*Vigma unguiculata*) (CP), groundnut (*Arachis hypogaea*) (GN), soyabean (*Glycine max*) (SOY) and one semi-perennial grain-legume species - pigeonpea (*Cajanus cajan*) (PP). Specific focus was placed on increased system diversification as well as integrated nutrient and agronomic management of sole and intercropped cropping-systems. The two studied cropping-systems were: 1) systems that contained only one crop species (SOLE system) and 2) systems that contained two or more intercropped species (INTER system). The five studied GLI sub-systems within cropping-systems were: 1) sole legume (L1), 2) sole maize (L0M), 3) mixed maize-legume intercrop with one legume (L1M), 4) mixed legume intercrop with two or more legumes (L2) and 5) farmer designed mixed maize-legume intercrop with two or more legumes

(L2M). Technologies within each sub-system that include both those demonstrated on Mother trials and those found on Baby trials are listed below in Table 2.3.

Table 2.3 Definition of systems, sub-systems and technologies.

System	Sub-system	Technology	Description
SOLE			monoculture
	L0M		monoculture maize
		MZ1	maize
	L1		monoculture legume
		BN1	bean
		CP1	cowpea
		GN1	groundnut
		PP1	pigeonpea
		SOY1	soyabean
INTER			polyculture
	L1M		maize intercropped with one legume
		MZBN	maize - bean
		MZCP	maize - cowpea
		MZGN	maize - groundnut
		MZPP	maize - pigeonpea
		MZSOY	maize - soyabean
	L2		two or more legumes intercropped
		BNGN	bean - groundnut
		BNSOY	bean - soyabean
		CPGN	cowpea - groundnut
		CPSOY	cowpea - soyabean
		GNSOY	groundnut - soyabean
		PPBN	pigeonpea - bean
		PPCP	pigeonpea - cowpea
		PPGN	pigeonpea - groundnut
		PPSOY	pigeonpea - soyabean
		BNCPGN	bean - cowpea - groundnut
		CPGNSOY	cowpea - groundnut - soyabean
		PPCPGN	pigeonpea - cowpea - groundnut
		PPCPSOY	pigeonpea - cowpea - soyabean
		PPGNSOY	pigeonpea - groundnut - soyabean
		PPCPGNSOY	pigeonpea - cowpea - groundnut - soyabean

Table 2.3 (cont'd)

System	Sub system	Technology	Description
	L2M		maize intercropped with two or more legumes
		MZBNCP	maize - bean - cowpea
		MZBNGN	maize - bean - groundnut
		MZBNSOY	maize - bean - soyabean
		MZCPSOY	maize - cowpea - soyabean
		MZCPGN	maize - cowpea - groundnut
		MZGNSOY	maize - groundnut - soyabean
		MZPPBN	maize - pigeonpea - bean
		MZPPCP	maize - pigeonpea - cowpea
		MZPPGN	maize - pigeonpea - groundnut
		MZPPSOY	maize - pigeonpea - soyabean
		MZBNCPSOY	maize - bean - cowpea - soyabean
		MZBNGNSOY	maize - bean - groundnut - soyabean

2.2.3 Baby Trial Selection

Over all four EPAs (Golomoti, Kandeu, Linthipe and Nsipe), a total of 363 Baby trial farmers were identified (as part of the Mother/Baby trial design described in the previous section of this chapter). Farmers were chosen by village leaders and extension agents in each section of the EPA. Female-headed households were of particular interest because previous research, in Malawi, has indicated that female-headed households have a greater potential for adopting legume technologies (Snapp et al., 2002b). Therefore, female-headed households were preferentially chosen in each section of the EPA, which accounted for 65% of the total farmer population. All participating Baby trial farmers were provided with improved seed varieties of all GLI legumes, free of charge, at the beginning of each growing season (~1kg farmer chosen species^{-1} farmer^{-1} year^{-1}). Farmers were asked to design their own experimental trials and to include a minimum of three experimental plots (EXP) containing farmer designed legume technologies with farmer chosen GLI legume(s) (as described in Table 2.2). Farmers were encouraged to integrate, adapt and innovate with demonstrated Mother trial technologies as they found appropriate for their on-farm context. In addition to these trials, during the second year of experimentation farmers, in the absence of project support, began integrating GLI legumes into their whole farm (TRADexp plots).

2.3 Data Collection:

2.3.1 Surveys and In-field Measurements

Two on-farm surveys were conducted post-harvest over the course of approximately 120 days (May-August), each at two-time points during the four years of farmer experimentation: one after two years of experimentation (2014) and one at the end of the four years (2016). The surveys were administered to farmers by researcher-trained Malawian enumerators at farmers EXP plots (plots were physically visited post-harvest 2014 and 2016). The questions in these survey instruments were initially developed by the researchers and refined and adjusted using key-informant interviews and small village-level focus group discussions. Questions posed to farmers in the 2014 survey were also posed during the 2016 survey. Information gathered in the 2014 open-ended survey (Appendix A) was used to inform the 2016 survey and resulting response codes were incorporated (Appendix B). In both surveys, farmer recall of the previous two-year cropping-system history was recorded for each EXP plot. This history included cropping-system inputs and procurement sources as well as farmers' agronomic practices, motivations, challenges and associated reasoning. In-field measurements of plot area and GPS location was obtained from EXP plots during their initial visit in 2014, while farmer reported area was used to determine TRADexp plot area.

During the 2016 survey, farmers' technology preferences, perceptions of technology contribution to farmers' livelihood attributes as well as farmers' agronomic motivations for GLI technology integration were explored. Livelihood attributes and agronomic motivations were identified through both focus group discussions as well as key informant interviews and were further confirmed during researcher participant observation. Farmers' technology preferences were determined using a farmer GLI technology ranking by pairwise comparison. Farmers' perceptions of the technologies' contribution to the identified livelihood attributes and farmers' ratings of agronomic motivations for cultivating GLI technologies were obtained (explained in sections 2.3.2, 2.3.3 and 2.3.4). It should be noted that due to project directive, only one technology from the L1 sub-system was explored in terms of its livelihood attributes. Household data and wealth indicators were also identified using key informant interviews with village leaders, agricultural officers, lead farmers and through on-farm researcher participant observation. These asset indicators were then incorporated into the survey instrument and farmers were then asked to quantify their possession of such indicators (e.g. livestock quantity, number of rooms and dwellings within compounds etc.). This information was then used to determine farmer livestock and asset units as follows, using a normalized and modified version of the Bill and Melinda Gates Agricultural Development Outcome indicators in conjunction with the CASHPOR House Index (BMGF, 2010):

a) Asset Index
   a. 0 & 1: 0 units = asset poor
   b. 3 & 4: 2 units = average asset holding
   c. 5 & 6: 6 units = asset rich

Asset Index = ∑ *[[total ox carts owned X (12 weight units)] + [total fenced livestock pens owned X (10 weight units)]*

+

[total pigeon pens owned X (8 weight units)]

+

[total bicycles owned X (6 weight units)]

+

(total radios owned X (2 weight units)]]

/

total mean

b) Livestock Index
   a. 0 – 2: 0 units = livestock poor
   b. 3 – 5: 2 units = average livestock population
   c. ≥ 6 : 6 units = good livestock population

Livestock Index = ∑ *[[total cattle owned X (10 weight units)] + [total sheep|goats owned X (3 weight units)]*

+

[total swine owned X (2 weight units)]

+

[total poultry owned X (1 weight unit)]]/ total mean

2.3.2 Technology Ranking by Pairwise Comparison

Farmers' technology preferences were explored using a ranking of technologies by pairwise comparison. All Mother trial technologies and the most frequently cropped technologies in 2013 and 2014 as well as sole maize were compared by each participant individually. Every technology within each sub-system was compared to one another as well as to sole maize by showing the farmer a jar filled with the corresponding crop seed(s) from each of the two technologies being compared and then asking the farmer to physically indicate by pointing to the jar whose seed(s) corresponded to the technology they found to be superior to the other. The technology that the farmer indicated superior, was then recorded by the enumerator on the data collection sheet. These individual comparisons resulted in the ranking of all of the compared technologies. Technology rankings were determined using the count of the occurrence of technology preference as a score for each individual technology. Odds ratios were obtained as the number of times the technology was preferred by the number of times a technology was compared. These ratios were then normalized and compared for statistical significance (Weke et al., 2006).

2.3.3 Livelihood Attribute Rating

Farmers rated six livelihood attributes that were obtained from previous PAR studies as well as focus group discussions and key informant interviews. These attributes were selected based off land productivity, economics, grain storability and food security. Farmers were given a card with markings that represented a continuous line scale and a smaller marker card. Farmers were then asked to place the smaller card on the larger scale card where they perceived the technology in question to fall along the continuous line in terms of the amount of contributions each technology had towards the specific livelihood attribute, location on the scale was recorded (Appendix B). The far-left end of the scale represented “no contribution at all” and the far-right end “a large contribution”. The following specific attributes were identified and subsequently rated by farmers: 1) yield of one acre, 2) labor of one acre, 3) food security of one acre, 4) income of one acre, 5) storage longevity of a hypothetical 50 kg bag of grain and 6) the nutritional value of the same bag.

The last exercise that was conducted to understand farmers’ perceptions of technology’s labor demand. Labor tasks vary between technologies and throughout the growing season. Therefore, farmers were asked to identify which of the four most common labor tasks (planting, weeding, harvesting or processing) they found to be the most labor intensive for each studied technology. The task was identified by the farmer and the response recorded on the data collection sheet.

2.3.4 Ratings of Agronomic Consideration for Grain-legume Integration

Using the same scale card as was used in the livelihood attribute exercise, farmers rated seven agronomic considerations for their importance as a motivator for farmers’ integration of GLI technologies. The far-left end of the scale represented “not important at all” and the far-right end of the scale represented “extremely important”. The following considerations were rated in terms of importance by farmers: 1) planting time of crop(s), 2) harvesting time of crop(s), 3) if a crop is prone to termite infestation, 4) if a crop is prone to insect attack, 5) if the crops have complimentary growth habits, 6) if a crop has the ability to suppress weeds and 7) crop soil amelioration contributions.

2.4 Statistical Analysis:

A Chi-squared test of association was performed in SAS 9.4 PROC FREQ to examine the association between grain-legume species present in technologies and EPA.

The following data analyses were conducted using SAS 9.4 PROC GLIMMIX. Specifications of the statistical models fitted to the data varied depending on the experimental settings and are listed below for each data analysis. Overall, the key studied groups in the analysis of variance, e.g., EPAs, technologies, cropping-systems and sub-systems were treated as fixed factors, while individual farmer effects were regarded as random factors.

To assess the differences among intercropping considerations, cropping-systems, sub-systems and technologies in terms of farmers' overall livelihood attribute's ratings of technologies, the statistical model included EPA, intercropping considerations, cropping-systems, sub-systems or technologies as fixed factors, farmer nested in EPA a random factor.

For assessing the differences in farmer technology preferences, SAS 9.4 PROC LOGISTIC was used to fit the cumulative logit Bradley-Terry statistical model (Weke, 2006).

The assumptions of normal distribution of the residuals and homogeneity of variances were checked in all data analysis.

2.5 Results:

2.5.1 General Site and Farmer Characterization

A total of 278 hectares of cultivated land was studied over the four years. Particular focus was on the 135 hectares cultivated in legume technologies. EXP plots occupied 42 hectares (15%) and TRADexp plots occupied 93 hectares (35%) of the total land area (Table 2.1). The average household size was 5.12 (members household^{-1}) with 47% of total household members available to contribute to labor. Overall mean land holding was 1.13 ha household^{-1}. Farmers reported possessing less than one tangible asset unit (0.83) and even fewer livestock units (0.36).

2.5.2 Farmers' Grain-Legume Integration

To determine farmers' integration of GLI technologies over the four years, we used farmers' cropping-system information from the two surveys conducted post-harvest in 2014 and 2016. The results indicated that the majority of all studied plots, both EXP and TRADexp, were cultivated in SOLE systems (79 and 71%, respectively), whereas INTER systems accounted for 21 and 29%, respectively (Table 2.4). Specifically, in EXP plots, L0M was the most frequently cropped sub-system (47%), followed by L1 (32%), L1M (15%), L2 (5%) and L2M (1%). The majority of GLI technology plots cultivated on both EXP and TRADexp plots contained GN and SOY. Thirty-seven percent of EXP plots and 36 % of TRADexp plots contained GN, while 25% of EXP plots and 29% of TRADexp plots contained SOY. Only 12% of EXP plots and 17% of TRADexp plots were cultivated in the newly introduced PP. (Table 2.4). Farmers reported having the least experience growing PP; only 13% of farmers indicated that they cultivated PP prior to the project's conception (2012), while 90% of farmers cultivated GN and 49% cultivated SOY. The majority of farmers reported being able to sell GN (63% of farmers) and SOY (59% of farmers), however only 14% of farmers are able to sell PP. More specifically, we found that the distribution of technologies containing specific species between EPAs were associated ($X^2{}_{,15}$ $p < 0.0001$). Farmers in Linthipe cultivated technologies containing BN more frequently and farmers in Golomoti cultivated CP more frequently than all other EPAs. All other cropped grain-legume species were distributed fairly evenly throughout all EPAs.

Table 2.4 Percentage of systems, sub-systems and technologies cultivated by farmers on EXP and TRADexp plots over four years by EPA. Technologies on EXP plots were determined by in-field visits and farmer recollection. Technologies on TRADexp plots were determined by farmer recollection without in-field visit.

System	EXP Plots					TRADexp plots				
Sub-system	Gol	Lin	Kan	Nis	Total	Gol	Lin	Kan	Nis	Total
Technology			%					%		
SOLE	77	65	79	89	79	70	65	77	70	71
L0M	61	55	56	63	60	---	---	---	---	---
MZ1	100	100	100	100	100	---	---	---	---	---
L1	39	45	44	37	40	100	100	100	100	100
BN1	0	4	1	0	1	0	0	0	0	0
CP1	18	12	5	8	10	18	18	5	12	13
GN1	49	44	45	53	48	42	39	47	38	41
PP1	6	4	15	12	10	11	4	13	16	12
SOY1	26	37	34	27	31	28	39	35	34	33

Table 2.4 (cont'd)

System Sub-system Technology	EXP Plots					TRADexp plots				
	Gol	Lin	Kan %	Nis	Total	Gol	Lin	Kan %	Nis	Total
INTER	23	35	21	11	21	30	35	23	30	29
L1M	84	63	67	55	69	71	19	71	40	51
MZBN	0	89	21	4	31	1	50	19	0	9
MZCP	63	2	14	38	31	58	8	19	26	37
MZGN	16	3	34	7	15	11	25	19	5	12
MZPP	11	3	8	28	10	23	0	8	23	18
MZSOY	10	3	23	24	13	7	17	33	47	24
L2	12	35	22	45	27	27	81	27	60	48
BNGN	0	12	0	0	5	0	12	0	0	4
BNSOY	0	0	0	0	0	0	0	7	0	1
CPGN	19	10	12	6	11	0	16	7	11	10
CPSOY	0	7	6	10	7	0	4	0	11	6
GNSOY	38	37	10	5	24	37	42	14	11	26
PPBN	0	1	0	0	0	0	0	0	2	1
PPCP	9	1	10	11	7	7	6	14	13	10
PPGN	19	19	33	31	25	41	14	43	36	30
PPSOY	13	5	27	34	18	7	2	7	14	8
BNCPGN	0	1	0	0	0	0	0	0	0	0
CPGNSOY	0	3	0	2	2	0	0	0	0	0
PPCPGN	0	0	2	2	0	4	0	0	0	1
PPCPSOY	0	1	0	0	0	0	0	0	2	1
PPGNSOY	3	2	0	0	1	4	2	7	2	3
PPCPGNSOY	0	0	0	0	0	0	2	0	0	1
L2M	4	1	11	0	4	2	0	2	0	1
MZBNCP	0	25	26	0	19	0	0	0	0	0
MZBNGN	0	0	13	0	8	0	0	0	0	0
MZBNSOY	0	25	17	0	14	0	0	100	0	33
MZCPSOY	0	0	4	0	3	0	0	0	0	0
MZCPGN	20	0	0	0	5	0	0	0	0	0
MZGNSOY	10	0	4	0	5	0	0	0	0	0
MZPPBN	0	50	0	0	5	0	0	0	0	0
MZPPCP	30	0	4	0	11	100	0	0	0	67
MZPPGN	10	0	4	0	5	0	0	0	0	0
MZPPSOY	30	0	17	0	19	0	0	0	0	0
MZBNCPSOY	0	0	4	0	3	0	0	0	0	0
MZBNGNSOY	0	0	4	0	3	0	0	0	0	0

2.5.3 Farmers' Preferences of Grain-Legume Technologies

To understand how the studied technologies ranked in terms of farmers' preferences, farmers ranked the technologies using a ranking by pairwise comparison. Farmers indicated that overall, they preferred INTER systems over SOLE systems. Farmers ranked L1 sub-systems significantly lower and

L0M sub-systems significantly higher than all other sub-systems (α=0.05) (Figure 2.3). Within INTER systems, farmers ranked the mixed legume (L2) sub-system significantly lower than the mixed maize-legume(s) (L1M ad L2M) sub-systems (α=0.05) (Figure 2.3). Notably, L1M sub-system technologies, MZSOY and MZGN, ranked significantly higher for farmers' preferences than all other technologies, including L0M technologies (α=0.05) (Figure 2.2). Additionally, there was no significant difference between L0M technologies and MZGNSOY or MZPP technologies (α=0.05) (Figure 2.2).

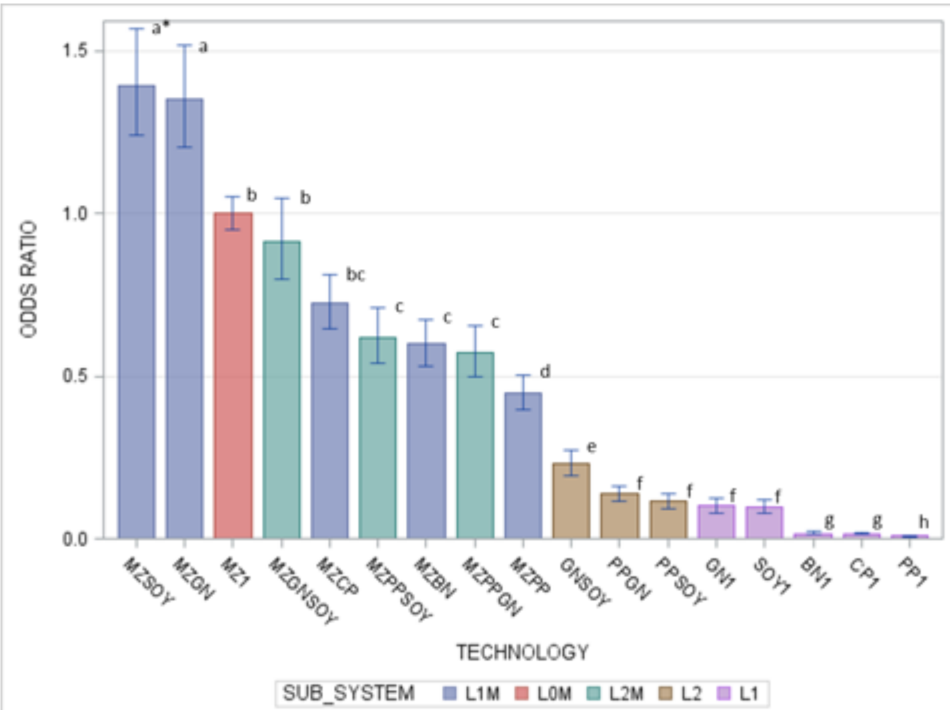

Figure 2.2 Results of farmers' technology preferences from their ranking by pairwise comparison of technologies. Error bars indicate a 95% confidence interval from the mean and odds ratios followed by the same letters are not significantly different (α=0.05).

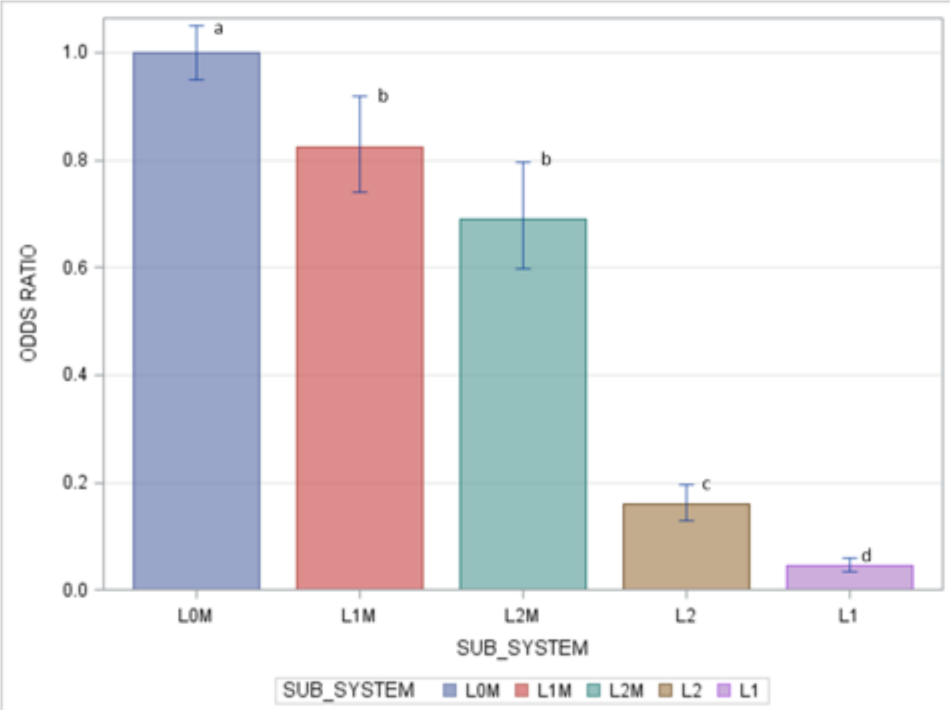

Figure 2.3 Results of farmers' ranking by pairwise comparison of technologies by sub-system. Error bars indicate a 95% confidence interval from the mean and odds ratios followed by the same letters are not significantly different (α=0.05).

2.5.4 Farmers' Perceptions of Technologies' Contributions to Livelihood Attributes

To determine farmers' perceptions of the studied technologies' contributions to the investigated livelihood attributes, farmers rated each technology's contribution to all six livelihood attributes. The results indicated that, the farmers perceived INTER systems to have a significantly greater positive contribution to their livelihoods than SOLE systems (α=0.05) (Table 2.5). Specifically, L1M sub-systems had a significantly higher positive overall livelihood contribution rating than all other sub-systems (α=0.05) (Table 2.5). When comparing the studied technologies to the traditional L0M technologies, L1M technologies MZSOY, MZGN and MZCP had a significantly higher livelihood contribution rating, while GNSOY, MZPP and PPSOY rated the same as L0M technologies (α=0.05) (Table 2.5). It should be noted that a full livelihood contribution analysis of the L1 sub-system was not possible. Farmers were not asked to rate any L1 technologies other than PP1, which had an overall rating that was significantly lower than all other technologies (α=0.05) (Table 2.5).

Table 2.5 Mean livelihood attributes ratings of systems' (Sys) , sub-systems' (Sub) and technologies' (Tech) contributions. † total means followed by the same letters are not significantly different (α=0.05), ‡ mother trial ON and NOT means followed by the same letters are not significantly different (α=0.05), ¶ system means followed by the same letters are not significantly different (α=0.05), § sub-system means followed by the same letters are not significantly different (α=0.05) and ¥ technology means followed by the same letters are not significantly different (α=0.05).

	Livelihood Attributes																		Aggregate Attribute Mean Rating		
	Nutrition Provided by one 50 kg grain sac			Storability of one 50 kg grain sac			Food Security provided by one acre			Yield provided by one acre			Income provided by one acre			Labor demand of one acre					
Total		4.28 [a†]			2.95 [b]			2.93 [b]			2.83 [c]			2.18 [d]			1.95 [e]			2.85	
ON Mother Trial		4.43 [a‡]			3.03 [c]			3.00 [c]			2.89 [d]			2.28 [f]			1.85 [i]			2.91 [a]	
NOT Mother Trial		4.09 [b]			2.86 [d]			2.66 [e]			2.61 [e]			2.07 [h]			2.16 [g]			2.74 [b]	
	Sys	Sub	Tech	Sys	Sub	Tech	Sys	Sub	Tech	Sys	Sub	Tech	Sys	Sub	Tech	Sys	Sub	Tech	Sys	Sub	Tech
SOLE	**3.88 [b¶]**			**2.81 [de]**			**2.91 [cd]**			**2.73 [e]**			**1.79 [i]**			**2.11 [g]**			**2.70 [a]**		
L0M		4.12 [c§]			2.81 [i]			3.78 [d]			3.55 [ef]			2.04 [no]			1.64 [q]			2.99 [b]	
MZ1			4.12 [c¥]			2.81 [qr]			3.78 [de]			3.55 [fgh]			2.04 [DE]			1.64 [JK]			2.99 [cd]
L1		3.64 [de]			2.81 [i]			2.03 [no]			1.90 [o]			1.53 [q]			2.57 [j]			2.41 [e]	
PP1			3.64 [f]			2.81 [qr]			2.03 [DEF]			1.90 [EFGH]			1.53 [K]			2.57 [tu]			2.41 [h]
INTER	**4.35 [a]**			**2.97 [c]**			**2.93 [c]**			**2.85 [d]**			**2.25 [f]**			**1.93 [h]**			**2.88 [b]**		
L1M		4.30 [b]			2.95 [h]			3.49 [f]			3.35 [g]			2.43 [kl]			1.92 [o]			3.07 [a]	
MZGN			4.41 [ab]			3.04 [lm]			3.58 [fg]			3.47 [ghi]			2.50 [tuvw]			1.88 [GHI]			3.15 [a]
MZCP			4.16 [c]			2.85 [opqr]			3.64 [ef]			3.54 [fgh]			2.50 [tuvw]			1.99 [DEFG]			3.11 [ab]
MZSOY			4.45 [ab]			3.04 [lm]			3.43 [hij]			3.22 [k]			2.48 [uvwx]			1.87 [GHI]			3.08 [b]
MZPP			4.19 [c]			2.88 [nopqr]			3.28 [jk]			3.16 [kl]			2.24 [AB]			1.94 [DEFG]			2.95 [d]
L2M		4.49 [a]			2.96 [h]			2.48 [jk]			2.38 [l]			2.00 [no]			1.76 [p]			2.68 [d]	
MZPPSOY			4.47 [ab]			2.91 [mno]			2.55 [tuv]			2.40 [uvwxy]			2.04 [DEFG]			1.78 [HIJ]			2.69 [f]
MZPPGN			4.46 [ab]			2.98 [mnopq]			2.52 [tu]			2.44 [vwxyz]			2.00 [DE]			1.76 [HIJ]			2.69 [f]
MZGNSOY			4.55 [a]			2.99 [mno]			2.38 [vwxyzA]			2.31 [yzAB]			1.94 [DEFG]			1.75 [IJ]			2.66 [f]
L2		4.29 [b]			3.00 [h]			2.71 [i]			2.71 [i]			2.27 [m]			2.06 [n]			2.84 [c]	
GNSOY			4.55 [a]			3.38 [ij]			2.88 [opqr]			2.84 [opgr]			2.48 [tuvwx]			1.93 [EFG]			3.01 [c]
PPSOY			4.37 [b]			3.03 [lmn]			2.85 [opqr]			2.83 [pqr]			2.43 [uvwxyz]			2.09 [CD]			2.93 [d]
PPGN			4.35 [b]			2.97 [mnop]			2.76 [rs]			2.81 [qr]			2.29 [zAB]			2.02 [DEFG]			2.87 [e]
PPCP			3.89 [d]			2.63 [st]			2.36 [wxyzA]			2.35 [xyzA]			1.89 [FGHI]			2.20 [BC]			2.55 [g]

In general, farmers rated the nutritional contributions of the studied technologies significantly higher and the labor contributions significantly lower than all other attributes (α=0.05) (Table 2.5). Within individual attributes, we found trends associated with maize-legume intercropped sub-systems that were reflected in the differences between farmers' attribute ratings of SOLE L0M technologies' attributes and maize INTER technologies (L2M and L1M). L0M technologies rated significantly higher than all other technologies in terms of food security and yield but significantly lower than all others for labor (α=0.05) (Table 2.5). Farmers' livelihood attribute ratings indicate that, when examining the differences between the individual attributes of L0M and MZ intercropped systems, the addition of one legume intercrop(s) to L0M significantly increased farmers' storability ratings and significantly reduced farmers' labor ratings (α=0.05) (Table 2.5). The addition of one or more legume intercrop(s) to L0M significantly decreased farmers' L0M yield rating, except for when the intercropped legume species was either CP or GN only, which had no effect on the farmers' yield ratings (α=0.05) (Table 2.5). Likewise, adding one or more legume intercrop(s), other than CP only, to L0M significantly decreased farmers' food security ratings (α=0.05) (Table 2.5).

2.5.5 Farmers' Perceptions of Labor Demand

Using informal focus group discussions, participant observation and researcher in-field participatory cultivation and observation, four common labor tasks were identified: weeding, planting, harvesting and processing. Farmers were asked to identify the most difficult task associated with for each of the studied technologies. Results of this exercise indicated that the majority of farmers identified weeding as the most difficult labor task (57%). L0M technologies were identified as the most difficult to weed and difficulty decreased with the increasing presence of legume intercropping (Figure 2.4). However, farmers identified L0M technologies as the easiest to harvest and plant and processing was the easiest task for all technologies (Figure 2.4). Planting difficulty decreased as the total number of crops present in the technology decreased. Harvesting difficulty decreased as the presence of MZ increased within technologies. That is to say that as the presence of maize became more dominant over legume(s) within the cropping-system, farmers perceived harvesting and planting to become easier.

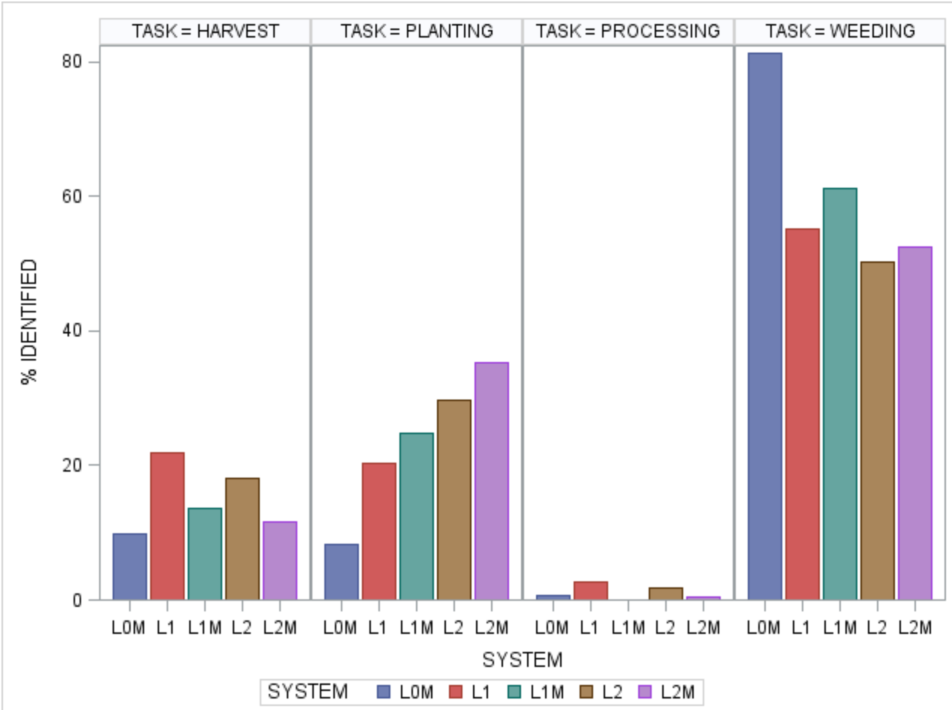

Figure 2.4 Results of farmers identified most difficult labor task associated with each technology by percentage identified by farmers for each technology within each sub-system.

2.5.6 Farmers' Agronomic Considerations for Grain-legume Integration

To understand farmers' motivations for integrating GLI technologies into their cropping-systems, farmers were asked to rate seven agronomic considerations: 1) planting time of all intercrop crops, 2) harvesting time of all intercrop crop, 3) if a crop is prone to termite infestation, 4) if a crop is prone to insect attack, 5) if the crops have complimentary growth habits, 6) if a crop has the ability to suppress weeds and 7) the crop's soil amelioration ability. We found that farmers' greatest motivation for legume integration was to increase soil fertility, which farmers rated significantly greater than all other considerations ($\alpha=0.05$) (Figure 2.5). Open ended survey questions revealed that farmers integrate grain-legumes in their whole farm plots that were previously cultivated in L0M technologies (TRADexp) because they believe that legumes have the ability to increase soil fertility and system biodiversity. Farmers also identified that limited land holdings often limit their legume integration.

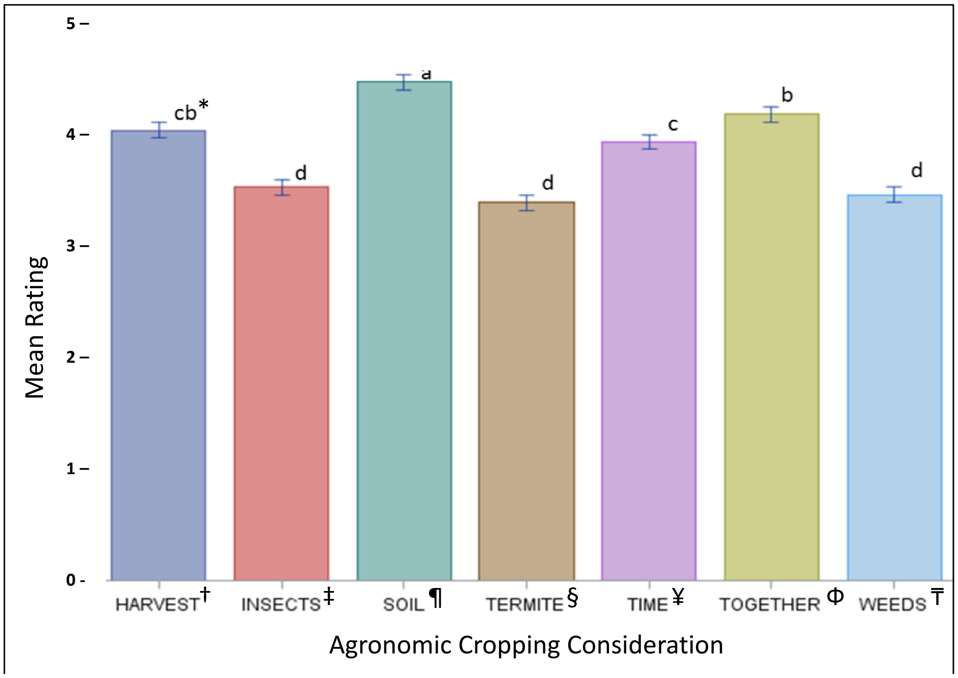

Figure 2.5 Results of farmers' ratings of agronomic considerations for GLI integration in terms of importance [0 (not important at all) to 5 (very important)] † Crop harvesting time, ‡ Insects associated with crop, ¶ Soil fertility associated with crop, § Termites associated with crop, ¥ Crop planting time, Φ Complementary grow habits of crop, Ŧ Crop ability to suppress weeds. Error bars indicate a 95% confidence interval of means.*means followed by the same letter are not significantly different (α=0.05).

2.6 Discussion:

2.6.1 Farmers' Preferences Compared to their Cropping-system Choices

In this study, farmers' stated technology preferences did not fully reflect their actual integration of GLI technologies. These findings are similar to the findings of Snapp et al., (2002b) who, explored farmers' potential uptake of legume technologies and found that although farmers' stated technology preferences indicated that farmers were interested in legume technologies, their uptake of them was minimal. These results are consistent with the findings of others who have explored farmers potential uptake of agricultural technologies (Franke et al., 2014; Kamanga et al., 2014; Snapp et al., 2002b). This phenomenon was also present in our study. For example, we found that farmers cultivated SOLE cropping-systems more frequently than INTER cropping-systems, yet farmers indicated that they prefer INTER cropping-systems over SOLE cropping-systems. More specifically, pertaining to only GLI technologies (SOLE maize not included), farmers cultivated LI technologies at a higher frequency than all others (L1M, L2M and L2 technologies), but indicated that they preferred these technologies over the most frequently cultivated L1 technologies. This trend was present in both the collaborative EXP plots as well as the farmer initiated TRADexp plots, suggesting that farmers' stated preferences are not reliable predictors or a reflection of their on-farm choices.

2.6.2 Farmers' Perceptions Compared to their Cropping-system Choices

Waldman et al., (2016) suggest that farmers' perceptions of grain-legume attributes may provide a clearer understanding of farmers' actual choices associated with grain-legume integration than that of farmers' stated preferences. There is strong evidence that farmers' non-adoption of legume technologies, despite their preferences for them, is associated with farmers' concerns pertaining to food security and potential additional labor demands associated with the integration of legumes into their cropping-systems (Droppelmann et al., 2017; Falconnier et al., 2016; Franke et al., 2014; Mhango et al., 2013; Snapp et al., 2010; Ogoke et al., 2009; Orr, 2003; Snapp et al., 2003; Snapp et al., 2002a; 2002b). Our findings also indicate that farmers prioritize food security and labor demand in their cropping-system choices, however it is farmers' perceptions of these attributes, as they are associated with specific technologies, that ultimately influences their cropping-system choices and not farmers' perception of aggregate livelihood attributes that determines their cropping-system choices.

Just as Waldman et al., (2016) suggest, we found that farmers' perceptions of the technology's contribution to individual livelihood attributes, specifically food security and labor demand influenced their actual cropping-system and not their preferences. When we analyzed farmers' perceptions of GLI technologies' contributions to livelihood attributes in aggregate, we found that farmers' perceptions of collective livelihood attributes did not reflect their cropping-system choices. For example, just as farmers preferred INTER cropping-systems to that of SOLE cropping-systems, in aggregate, farmers perceived INTER cropping-systems to have a greater positive contribution to the studied livelihood attributes than that of the SOLE cropping-systems. However, when these livelihood attributes were disaggregated we found that farmers' choices, associated with the studied GLI technologies, generally reflected a logical consideration of diverse types and prioritization of factors based on their lived realities. This was reflected in their perceptions of livelihood attributes associated with the GLI technologies and farmers' cropping-system choices. For example, farmers in this study perceived SOLE maize to have the greatest contribution to their food security and subsequently prioritized maize-based food security by cultivating SOLE maize at the highest frequency comparative to all other technologies. This is logical because the yield of sole maize is typically double that of any of the studied GLI technologies per area of land and is consistent with the findings of others, in that Malawian farmers associate maize with food security (Ortega et al., 2016; Derlagen and Phiri, 2012). Moreover, it is well known that maize is the staple food of Malawi. The most common carbohydrate-based food in Malawi is a hard porridge made from maize (nsima) and as such, there are deep cultural and social traditions associated with it. Although rural Malawians do eat other foods in addition to nsima, such as grain-legumes, rice and vegetables, many rural Malawians do not consider their meal to be complete or food secure unless it does contain nsima. In fact, when we asked farmers why they prefer SOLE maize over other technologies during the pairwise comparison exercise, the majority of farmers responded, "because maize is life". This sentiment is reflected not only in the current and historically maize dominated landscape, but it is also reflected in farmers' perceptions associated with the food security attributes of SOLE maize. In a food insecure system like that of Malawi (FAO, 2016a), it stands to reason that farmers would cultivate the technology that they perceived to have the ability to provide the most food security, regardless of its requirements.

2.6.3 Farmers' Perceptions of Cropping-system Labor

Farmers perceived the labor demands of SOLE maize to be the greatest of all of the studied technologies, conversely, farmers perceived the labor demands associated with SOLE legume technologies to be the lowest of all GLI technologies. Farmers further indicated that they perceive weeding to be the most difficult labor task, specificall, in SOLE maize. SOLE legume technologies had a lower weeding demand than SOLE maize and INTER legume technologies had the lowest weeding demand of all GLI technologies. Therefore, labor associated with weeding does not fully explain farmers' cropping-system choices. For example, if weeding demand fully explained farmers' cropping-system choices, we would expect that farmers would be primarily cultivating INTER systems more frequently than SOLE systems – this is not the case.

Farmers' perceptions of the other labor tasks indicated that planting was the second most demanding labor task, where SOLE maize required the least amount of labor for planting, while INTER cropping-systems required the most - leaving SOLE legumes requiring the least planting labor of all GLI sub-systems. These findings suggest that farmers may be cultivating SOLE legume technologies for their minimal increases to cropping-system labor demand, specifically in terms of planting. However, in this study farmers not only perceived SOLE legume technologies to have the fewest positive contributions to their livelihood attributes, they also preferred them least among all GLI technologies. Although farmers perceived SOLE legumes to be the easiest system in terms of labor, including them does increase cropping-system labor demands without any other clearly identified attribute benefits. Therefore, this phenomenon calls for a deeper investigation of why farmers would integrate SOLE legumes into their systems at all.

2.6.4 Farmers' Perceptions and Knowledge Base

Agricultural research and development's initial motivations for the promotion of legume integration in smallholder cropping-systems was that of soil amelioration (Vanlauwe et al., 2017). It has been repeatedly reported that livelihood factors, like food security and labor demand, are of greater importance to farmers than soil fertility. The earlier promoted agricultural technologies did not include grain-legume varieties to that addressed these factors and may partially explain their non-adoption (Kamanga et al., 2014; Snapp et al., 2002a; 2002b;). For example, it has been found that legume technologies that do not positively contribute farmers' livelihood needs but improve soil fertility usually have minimal adoption (Vanlawe et al., 2017). Generally, through various biological processes, the integration of legume technologies can improve the long-term soil fertility of smallholder farming-systems with minimal additional inputs – resulting in increased yields and decreased labor demands (Franke et al., 2014; Kassie et al., 2014; Bezner-Kerr et al., 2007). However, the primary extension message received from farmers by Malawi Agricultural Extension, pertaining to grain-legumes, promotes them for soil amelioration (Malawi Ministry of Agriculture, 2012).

As a result, there has been extensive research efforts to increase the value of legume technologies that goes beyond soil fertility and addresses food security by including grain-legumes. There is a growing body of evidence, which suggests that farmers do value grain-legumes for their soil amelioration properties, specifically semi-perennial varieties (Waldman et al., 2017; Mhango et al., 2012). Our research demonstrates that, in addition to semi-perennial varieties, farmers also value annual grain-legumes and consider planting them as a soil amendment strategy. As evidenced by farmers' ratings of agronomic considerations for GLI integration in this study, farmers' primary agronomic reason for incorporating grain-legumes into their maize based cropping-systems is for their soil amelioration properties. These results further explain farmers' integration of SOLE legume technologies at a higher frequency than their preferred and perceived superior INTER legume technologies. That is to say that, although the integration of GLI technologies increases farmers' cropping-systems' labor demands. Farmers are willing to integrate them for long-term soil health as long as their maize production is maintained or increased. Yet, Snapp et al., (1998) caution that grain-legumes, because of their nitrogenous above-ground harvest, add little if any beneficial nitrogen to the soils and that specific management strategies such as integrated soil fertility management or a legume intercropped technology are necessary. Moreover, many studies have found that Malawian smallholder grain-legume harvesting often involves plant uproot and removal without return to field and heavily caution that without proper management of post-harvest grain-legume residues, soils can become more acidic and further depleted of key nutrients (Mungai et al., 2016; Ncube et al., 2009; Ojiem et al., 2007; Randall et al., 2006; Bezner-Kerr et al., 2007).Therefore, it is imperative that researchers and farmers are clear as to the management strategies necessary for the success of these heavily promoted GLI technologies in Malawi.

2.6.5 Farmers' Perceptions of Technology Attributes as they Align with Scientific Evidence

Farmers' cropping system choices are logical perceptions of each technologies' contribution to their livelihood attributes yet, these perceptions are often not aligned with the scientific evidence. This study provides strong evidence that a misalignment exists. Additionally, it reveals the potential consequences and reiterates the many challenges previously identified by farmers. Results of collaborative on-farm research indicate that these challenges can be mitigated by the integration of grain-legumes in maize-based systems (Bezner-Kerr et al., 2007). However, farmers' in this study did not have the same perceptions and as a result of their cropping-system choices did not reflect these findings. This disconnect between farmers' and researchers' understandings of the benefits associated with GLI technologies not only affects farmers' management decisions it also limits their adoption. Additionally, we propose that this misalignment between farmers' and researchers' perceptions of the technology's contribution to farmers' livelihoods, specifically farmers' short-term needs, like food security and labor demand. could have an effect on the direction of future research efforts. For example, farmers have repeatedly expressed their concerns about the decreased maize yield and increased labor demands associated with legume technology integration (Bezner-Kerr et al., 2007; Mhango et al., 2012; Snapp et al., 2002a; 2002b), yet research indicates that GLI technology integration in maize-based systems, at minimum, maintains yield and often results in an increase in both yield and labor use efficiency. However, farmers continue to perceive GLI technologies as negatively affecting maize yield and increasing cropping-system labor use efficiency (Liu and Basso, 2017; Smith et al., 2016; Franke et al., 2014; Snapp et al., 2002b; Phiri et al., 1999) and therefore limit their integration.

2.6.6 The Effects of Farmers' Available Knowledge on Farmers' Perceptions

The reasons for the disconnect between farmers' perception of GLI technologies and research findings are beyond the scope of this study. It is important to note that, in Malawi, there have been efforts to bridge this gap by creating a network of actors designed to increase the dissemination of research findings. Farmers' primary source of agricultural knowledge and newly developed information is obtained from this network through governmental agricultural extension agents. Malawi agricultural extension is resource limited and often is not able to or reach the most vulnerable members of the population (Mapila et al., 2016; Kassie et al., 2015; Hockett et al., 2014). The Malawian National Agricultural Research Network is a network of various actors, which include: the Malawian Department of Agricultural Research Services, the Consortium of International Agricultural Research Centers, Academia as well as private companies and organizations. It has been found that often the activities of many of these actors are not shared among them or with farmers (Mapila et al., 2016). The lack of fluid information sharing within the network could lead to farmers' inability to access valuable information pertaining to newly developed technologies because it often is not disseminated from this network to agricultural extension agents. In the absence of adequate information, farmers are left with few available options and a limited understanding of new (Gowing and Palmer, 2008). We suggest that this may be contributing to the misaligned perceptions between farmers and researchers seen in this study. Furthermore, research has shown that with access to agricultural knowledge and information, poverty can be reduced by nearly 1% in SSA (Alene and Coulibaly, 2009). Therefore, in an effort to realign farmers' and researchers' perceptions, we recommend that increased efforts to inform farmers of both the beneficial properties and cautionary management strategies associated with not only GLI technologies, but all developed technologies, be at the forefront of Malawian National Agricultural Research Network's efforts.

2.7 Conclusion:

In this study we observed that the use of participatory action research can easily determine farmers' preferences, however those preferences are not a clear indication of whether or not farmers will adopt the technologies of interest or realize the benefits. This is important because many developed agricultural interventions are driven by farmers' preferences. This study examined technologies that were developed over two decades with farmers and that farmers identified as potential adoptable technologies, yet farmers' practices did not reflect these preferences, rather their perceptions did. Moreover, this study revealed that farmers prioritize maize yield for food security and continue to primarily cultivate it over all GLI technologies, regardless of its labor demands. Suggesting that farmers are primarily using sole cropped legume technologies as a soil amelioration strategy, despite the overwhelming scientific evidence that other GLI technologies in this study not only have the ability to both maintain or increase maize yield but simultaneously increase soil fertility. Therefore, we conclude that farmers' lack of appropriate knowledge is affecting their cropping-system choices, specifically their integration and management of GLI technologies. We call for a more stream-lined communication system within the agricultural research and development community that effectively communicates both technology management strategies as well as the accompanying research knowledge to farmers so that they can make informed decisions pertaining to their cropping-system choices that are aligned with scientific research, which has been carefully designed to meet farmers' previously identified needs.

CHAPTER THREE

MALAWIAN SMALLHOLDER FARMERS' MANAGEMENT RESPONSES TO SOIL FERTILITY PERCEPTIONS

Abstract:

Despite efforts to increase soil fertility in central Malawi, soil fertility remains low, heterogeneous across plots, and farmers continue to produce marginal yields, which result in persistent yield gaps. This study was designed to explore how farmers' perceptions of soil fertility influence their integration of grain-legumes into their maize-dominated cropping-systems. A variety of physical and chemical soil properties were measured on farmer-identified high-fertility continuous maize, low-fertility continuous maize and grain-legume collaborative research plots. Foremost, we found that farmers' perceptions of soil fertility coincided with scientific indicators of soil fertility; farmer identified high-fertility soils had higher levels of total nitrogen and total organic carbon. As such, farmers' perceptions of soil fertility strongly influenced farmers' cropping-system management decisions. In this study, farmers not only preferentially allocated maize-based systems to higher fertility soils than their collaborative grain-legume research plots, they applied soil amendment resources to maize-based plots more frequently than grain-legume plots.

We suggest that farmers' preferential allocation of cropping-systems based on soil fertility may be an indication that farmers are intentionally using higher fertility soils as a strategy to increase their maize production and integrating grain-legume technologies as a soil amelioration strategy in their low fertility soils. However, without proper management these strategies are known to further degrade soils and therefore we suggest that both extension and researchers intensify their farmer education efforts beyond that of demonstration plots and more towards the underlying agroecological principles associated with both recommended and farmers' management strategies. This not only has the potential to increase technology uptake, but it may also provide farmers with the knowledge necessary to increase their overall cropping-system productivity based on sound scientific principles, without the assistance of researchers.

3.1 Introduction:

Although Malawian soils are not well suited for low input, continuous maize monocropping, smallholder farmers continue to grow traditional maize crops of variable yield on these marginal lands (FAO, 2016b; Snapp, 1998). On-farm collaborative research is an important tool for testing technologies that are designed to meet the many challenges faced by smallholder farmers (Vanluawe et al., 2017). Specifically, on-farm collaboration with farmers allows for technologies to be investigated in the context in which they are ultimately designed for. In addition, this approach allows for a clearer understanding of farmers' management choices, including their preferential allocation of cropping systems and soil amendments, which play an important role in maintaining soil fertility and land productivity. Yet, the reasoning behind farmers' cropping choices with respect to plot allocation is often unknown to researchers and can mislead research efforts devoted to increasing soil fertility and agricultural production (Roling, 2009).

Farmers employ adaptive strategies, which enable them to make conscious decisions that incorporate their own experiences and knowledge with their experiences with research technologies in order to create technologies that align with their livelihood needs. These decisions lead to technology adoption and adaptation which can have a direct effect on soil fertility (Roling, 2009; German et al., 2006). It has been suggested that one of the key factors driving farmer management choices may be farmers' perception of soil fertility; that is, farmers' allocation of available resources based on their perceived soil fertility needs and the plot's production potential (Tittonell et al., 2008; Tittonell et al., 2007; Mowo et al., 2006; Tittonell et al., 2005). Often, this preferential allocation results not only in a management gradient but also a production gradient that shifts spatial patterns of soil fertility (Tittonel et al., 2005). These soil fertility gradients can be particularly challenging for researchers who aim to address stagnant yield gaps on these low-productive soils. Farmers' management decisions can reinforce this soil heterogeneity and therefore technical recommendations must be diverse and targeted, which has become an increasing challenge for farmers, researchers and extension agents.

Researchers' understanding of farmers' perceptions of soil fertility is essential for the success of new agricultural interventions. Several on-farm studies have found that in mixed livestock cropping systems, due to limited resources and labor constraints, farmers preferentially allocate their high-value crops and available soil amendment resources to soils they perceive as being higher in fertility and are closer in proximity to the home (Tittonell et al., 2008; Mowo et al., 2006; Tittonell et al., 2005). These strategies have resulted in on-farm soil fertility gradients that do two things: 1) they maintain or improve soils, that are determined to be more fertile and 2) they often degrade those perceived as less fertile (Tittonell et al., 2008). Conclusive drivers of such management decisions are still not fully known; however, it has been suggested that soil texture, proximity to household and indigenous indicators (e.g. soil color and standing weed species) may be the key drivers of farmers' perceptions of soil fertility (Tittonell et al., 2008; Tittonell et al., 2005; Mowo et al., 2006). More specifically, Mairura et al., (2008) found that farmers perceived soil fertility is not associated with soil texture but rather soil chemical and biological properties. To further understand farmers' perceptions of soil fertility and resulting management choices, researchers are increasingly conducting collaborative on-farm research with farmers. However, even with these efforts farmers are still experiencing sub-optimal yields.

A question of particular concern is how farmers' perception of soil fertility affects their allocation of collaborative research plots. This is important because in addition to understanding farmers' management decisions, a key reason for conducting collaborative on-farm research is to emulate farmers' cropping-system environment so that developed technologies are relevant to both farmers' livelihoods and environmental contexts. Often, collaborative research focuses on new management strategies or crops that are unfamiliar or are not of high value to farmers. To understand how farmers' perceptions of soil fertility affect their management and their collaboration on-farm with researchers, we explored farmers' active on-farm experimentation of grain-legume integration (GLI) technologies over four growing-seasons using participatory action research (PAR). These technologies have been developed over the last two decades on-farm with farmers to increase soil fertility (Smith et al., 2016; Mhango et al., 2013; Malawi Ministry of Agriculture, 2012; Snapp et al., 2010; Ogoke et al., 2009; Snapp et al., 2003; Snapp et al., 2002b).

The study's objectives were to: 1) understand farmers' perceptions of soil fertility of farmers' identified high and low-fertility plots cultivated in traditional continuous maize monocropping; 2) determine farmers' management choices that reinforce their soil fertility gradient; 3) understand the patterns in terms of edaphic properties of plots; 4) explore the effects of farmers' perceptions of soil fertility on their management choices of GLI technologies and soil amendments in collaborative plots.

We hypothesized that plots perceived by the farmer as high-fertility will possess a finer soil texture (lower sand and higher clay and silt content). Thus, farmers will preferentially allocate experimental plots to coarser textured soils while traditional maize plots to finer textured soils, for farmers prioritize maize monocrop-systems and, therefore allocate them to soils perceived as more fertile. Additionally, farmers will experiment with GLI technologies that are more legume intense than their traditional systems on those soils that they perceive to be of lesser quality as a soil amelioration strategy. Farmers' perceptions of soil quality will be reflected in soil texture, levels of soil organic matter (SOM), total soil nitrogen (N), total soil carbon (C), cation exchange capacity (CEC), C: N and the % base saturation (BS). Specifically, the legume intense systems will be preferentially placed on soils with higher sand, lower SOM, lower total soil N, lower total soil C and a lower CEC and BS. Moreover, farmers prioritization of maize monocrop-systems over grain-legume cropping-systems will result in soil amendment resource allocation primarily to maize and not legume systems. Finally, due to labor constraints the Malawian soil fertility gradient will be associated with the plots' distance from main dwellings; plots closer to the main dwelling will be farmer defined as high-fertility plots and will possess soil qualities associated with greater soil fertility.

We found that ultimately, farmers perceptions of soil fertility were strongly related to many soil properties known to be associated with soil fertility. As such, when collaborating with researchers on-farm, farmers preferentially allocated their maize-based cropping-systems to higher fertility and subsequently preferentially allocated their available soil amendment resources to maize cropping-systems; suggesting that farmers may be using soil fertility status as a strategy to increase their maize production. Additionally, farmers' allocation of GLI technologies to lower fertility soils without proper amendment application may indicate that farmers are using GLI technologies as a soil amelioration strategy on their low fertility soils.

3.2 Methods and Materials:

The overall experimental design of this study is an unbalanced completely randomized design with cropping systems, soil amendment strategies, plot types and soil fertility levels as the studied factors. Experimental sites for the study were selected based on a production potential gradient in early 2012 and the study's implementation began in 2012-2013 growing season. Two districts of central Malawi were selected for the project (Dedza and Ntcheu). Within each district, two extension planning areas (EPA) were selected. (Mungai et al., 2016; Hockett et al, 2014). The EPAs represent four sub-humid agroecozones along a production potential gradient (marginal, moderate and high) based on the following parameters: 1) market access, 2) altitude, 3) dominant soil texture, 4) daily evapotranspiration rate (1°) and 5) cumulative annual unimodal precipitation. EPA altitudes ranged from 546-1244 meters above sea level, with annual precipitation levels ranging from 800-1006 mm of rain year^{-1} and located 27-90 km apart (Figure 3.1 &Table 3.1).

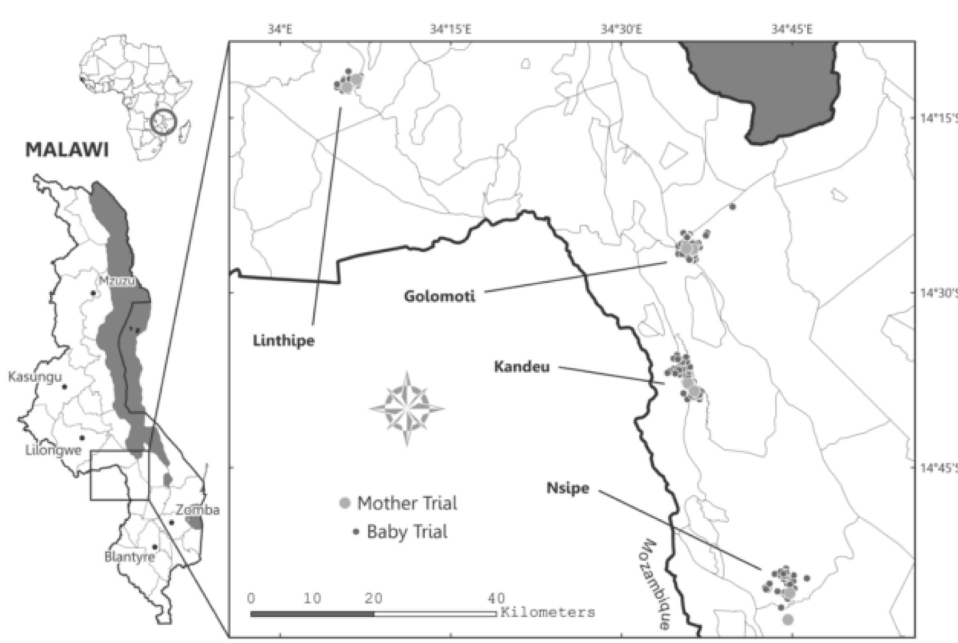

Figure 3.1 Map of Africa RISING-MALAWI Mother and Baby trial locations in four agricultural Extension Planning Areas
(*Map courtesy of Brad Peter, Michigan State University. 2017. Department of Geography*)

Table 3.1 Description of EPA production potential attributes, original and participating farmers counts, experimental and farmer-initiated plot counts, the area of studied landholding, and the total landholding by plot type and farmers per District and EPAs within Districts †(Mungai et al., 2016) ‡(Hockett et al., 2014).

District	Dedza		Ntcheu	
EPA	Linthipe	Golomoti	Kandeu	Nsipe
Production Potential	high	marginal	moderate	moderate
Parameter				
Distance from market (km from EPA center)†	5	1	2	9
Elevation (meters above sea level)†	1238	555	904	868
Dominant soil texture (USDA classification)‡	Loamy Clay	Loamy Sand	Sandy Clay	Sandy Clay
Daily evapotranspiration rate (mm)†	595	960	800	810
Annual rainfall (mm)‡	1006	891	800	811
Baby farmers and trials (n)	59	65	83	81
EXP plots (n)	310	224	316	336
TRAD farmers (n)	68	76	78	75
TRAD plots (n)	136	152	156	150
Total area EXP plots (ha)	16.5	7.4	12.2	5.5
Total area TRAD high-fertility plot $^{-1}$ (ha)	13	17.64	18.91	14.92
Total area TRAD low-fertility plot $^{-1}$ (ha)	14.22	18.59	21.77	18.37
Mean area EXP trial^{-1} (ha)	0.19	0.11	0.15	0.07
Mean area TRAD high-fertility plot $^{-1}$ (ha)	0.22	0.24	0.28	0.24
Mean area TRAD low-fertility plot $^{-1}$ (ha)	0.20	0.23	0.24	0.20

3.2.1 Mother Baby Trial Approach

The Mother / Baby participatory action research approach was used to introduce the grain-legume integration (GLI) technologies (further described in section 3.2.2) to farmers in November of 2012 (Bezner Kerr et al., 2007; Snapp, 2002). GLI technologies were introduced to Baby farmers using on-farm demonstration trials (Mother trials). Researchers and extension agents identified lead farmers to participate as Mother trial farmers in each EPA. The Mother trials were located in a visible and easily accessible location in each EPA [n=8 Mother trials in 2012-2013 growing season (two trials EPA^{-1})] and contained recommended GLI technologies (Snapp et al., 2017). The experimental design of all established Mother trials was a randomized complete block design (RCBD) with three replications and twelve 10m X 10m treatments per trial (Table 3.2). All 13 treatments (GLI technologies and sole maize technologies) were planted on Mother trials with participating Baby trial farmers as a farmer field day event at the beginning of every growing season. Mother trials served as a tool to meet both the research agenda and provide a farmer accessible location for technology demonstrations. Farmers participated during farmer field days where the suggested management of the technologies was explained and demonstrated so that farmers were able to glean information about the technologies and recommended management. The goal was to inspire Baby farmers to innovate and adapt the GLI demonstrated technologies in their own individual on-farm context (Bezner Kerr et al., 2007; Snapp, 2002).

Table 3.2 GLI technologies and applied soil amendment application demonstrated on Mother trials classified by sub-systems within systems. NPK fertilizer compound (23:21:0) and manure was locally sourced and varied by variety (cattle, pig, goat, sheep and chicken).

System	Sub-System	Technology	Soil Amendment
SOLE	L0M	MZ1	None
SOLE	L0M	MZ1	NPK 100 kg ha^{-1} + UREA 100 kg ha^{-1}
SOLE	L0M	MZ1	Manure 3-5 Mg ha^{-1} + UREA 100 kg ha^{-1} + NPK 100 kg ha^{-1}
SOLE	L1	PP1	NPK 50 kg ha^{-1}
SOLE	L1	BN1	NPK 50 kg ha^{-1}
SOLE	L1	CP1	NPK 50 kg ha^{-1}
SOLE	L1	GN1	NPK 50 kg ha^{-1}
SOLE	L1	SOY1	NPK 50 kg ha^{-1}
INTER	L2	PPCP	NPK 50 kg ha^{-1}
INTER	L2	PPGN	NPK 50 kg ha^{-1}
INTER	L2	PPSOY	NPK 50 kg ha^{-1}
INTER	L1M	MZPP	NPK 50 kg ha^{-1}
INTER	L1M	MZBN	NPK 100 kg ha^{-1} + UREA 100 kg ha^{-1}

3.2.2 Experimental Setup

3.2.2a Grain-Legume Integration Cropping Systems

Two cropping systems were studied 1) traditional maize (L0M) and 2) GLI systems. The L0M cropping system consisted of a continuous maize (*Zea mays*) monocrop managed per farmers' practice. The GLI technologies used improved seed varieties of four widely grown annual grain-legume species: common bean (*Phaseolus vulgaris)* (BN), cowpea (*Vigma unguiculata*) (CP), groundnut (*Arachis hypogaea*) (GN) and soyabean (*Glycine max*) (SOY) and one semi-perennial grain-legume species - pigeonpea (*Cajanus cajan*) (PP). These species were used to create three cropping-systems: 1) sole and mixed legume, 2) sole maize and 3) mixed maize-legume intercropped systems. Each of the three systems had one or two studied sub-systems as follows: sole and mixed legume sub-systems [sole legume (L1) and mixed legumes (L2)], sole maize sub-system [sole maize (L0M)] and mixed maize legume intercropped sub-systems [mixed maize legume intercrop with one legume (L1M) and mixed maize legume intercrop with two or more legumes (L2M)].

3.2.2b Studied Soil Amendment Strategies

Soil amendment strategies demonstrated on Mother trials are described in detail in Table 3.2 and consisted of various rates of inorganic N fertilizer application and integrated strategies. The four studied farmer soil amendment strategies were: 1) no amendment application (NO), 2) sole organic application (ORG) that included animal manure and or kitchen scrap compost, 3) sole inorganic application (INORG) that included NPK and or UREA, and 4) an integrated organic and inorganic (INTEG) application that included any of the ORG amendments and any of the INORG amendments combined and applied together. All fields had ubiquitous weeds and remaining crop residues incorporated into the soil at the time of field preparation.

3.2.2c Plot and Farmer Types

A total of 1780 plots from 525 farmers were included in this study (farmer and plot selection explained later in this section). There were two types of plots: 1) farmer identified high (H) and low (L) fertility continuous maize plots (TRAD plots) and 2) farmer and researcher collaborative GLI experimental plots (EXP plots). There were three farmer groups: 1) farmers whose traditional maize fields were monitored by the team of researchers and were not actively experimenting with researchers (TRAD farmers), 2) farmers who were only actively experimenting with researchers but whose maize fields were not being monitored (Baby group 2) and 3) farmers who were both experimenting with researchers and having their maize fields monitored (Baby group 1) (Figure 3.2).

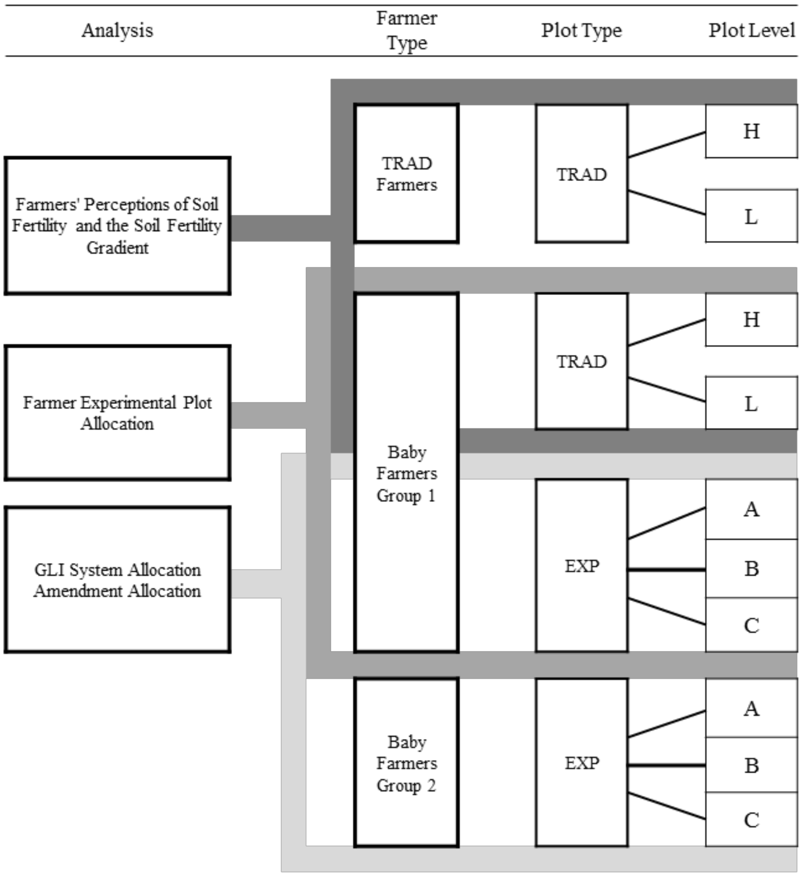

Figure 3.2 Plot types within farmer types by specific analysis conducted.

3.2.2d Experimental Farmers and Plots

Baby farmers (n=363) were chosen by village leaders and extension agents to cultivate their own experimental trials in each section of each EPA. Farmers were encouraged to integrate, adapt and innovate with demonstrated GLI technologies as they fit in their on-farm context. Female-headed households were of particular interest because previous research in Malawi has indicated that female-headed households have a greater potential for adopting legume technologies (Snapp et al., 2002b) and, therefore preferentially chosen in each section of each EPA and accounted for 65% of the total Baby farmer population. Each farmer had one trial that consisted of a minimum of three EXP plots: two plots containing farmer-chosen GLI technologies and one plot containing the L0M system. Farmers chose an area of land on their farms for the trials. The average area of each trial was equal to 0.13 ha and was calculated as the sum of all plots present in the trial. The average plot size was 0.04 ha. In all, there was

41.6 ha cropped in experimental trials across the two districts of central Malawi, with of a total of 1186 plots (Table 3.1).

3.2.2e Traditional Farmers and Plots

Farmers who cultivated TRAD plots (n=324) where randomly chosen from two farmer groups over the four EPAs (162 famers experimenting with researchers and 162 farmers not experimenting with researchers), 70% of the total farmers were female. The farmer perceived soil fertility status of each TRAD plot was determined by asking the farmers to each identify two continually cultivated maize plots on their farm they perceived to have differing soil fertility for monitoring only. The average plot size of the high-fertility plots was 0.25 ha and 0.22 ha for low-fertility plots (Table 3.1). Soil samples were collected from all TRAD farmers' H and L plots post-harvest between August and September of 2014 and analyzed as described later in section 3.3.2.

3.3 Data Collection and Processing:

3.3.1 In-field Measurements

For the ease of locating each household and studied plot during future visits, global positioning satellite (GPS) coordinates were collected using a Garmin eTrex 10 Worldwide Handheld GPS Navigator from the main dwelling front door in 2013. GPS coordinates for H and L fertility plots identified by TRAD farmers and for Baby farmer EXP trials were obtained from the center of each plot/trial in 2014. To obtain the area of all plots within each farm, the farmer walked the outside perimeter of the each of their plots holding the GPS unit.

3.3.2 Soil Sampling and Processing

In 2014 post-harvest soil samples were collected from farmer identified H and L plots of each participating TRAD farmer. A soil core sample was obtained from 0-20cm depth from the center of the cropping ridge at eight random locations within each plot using a trowel and composited. Samples were air-dried at room temperature (~26^{o}C) until constant moisture was reached. Soils were then processed for soil particle size analysis using the hydrometer method (Gee and Bauder, 1986). Soil pH was measured with a Fisher Scientific ™ accumet ™ AB250 using the Australian Department of Natural Resources soil survey standard test method for 1:5 soil: water suspension (Rayment and Higginson, 1992) at Chancellor College, Zomba, Malawi. Total organic carbon (TOC) and nitrogen (TN) were determined using combustion with the LECO ® TruMac CN Series Macro Determinator at The University of Michigan (LECO, 2014).

In 2014, post-harvest soil samples were collected from two randomly selected GLI plots in each EXP trial and from one corresponding continuous maize plot. For a few farmers (12-21 per EPA), only one EXP plot was sampled due to various in-field challenges. A soil core sample was obtained from 0-20cm depth from the center of the cropping ridge at eight random locations using a 1-inch diameter soil probe and composited from each sampled EXP plot. EXP soil samples were treated the same as TRAD samples and particle size distribution was measured using the same method as TRAD soils at Lilongwe University of Agriculture and Natural Resources, Bunda Campus, Malawi. Soil pH was measured at Michigan State University using the same method as the TRAD samples. Biological assays using 2 M Potassium Chloride (KCL) extractions and photospectrometer were used to determine total inorganic N and potential N mineralization at Michigan State University using the Snapp Lab modified version of Drinkwater et al., (1996) total inorganic nitrogen and seven-day ammonium (NH_4^+) (potentially mineralizable anaerobic nitrogen assay for soil).

Due to cost constraints, the following subset of EXP soils (n=320) was further processed from each EPA: 1) twenty high legume intensity in both 2013 and 2014 growing season (two or more legumes intercropped in both seasons), 2) twenty medium legume intensity (two or more legumes intercropped in 2013 growing season followed by a rotation of sole maize in the 2014 growing season) and 3) twenty low legume intensity (continuous sole cropped maize of an adjacent field of the same farmer in both 2013 and 2014 growing seasons). Soil TOC and TN were measured using the same method and machine as the TRAD soils. Mehlich III was used to determine cation exchange capacity (CEC), phosphorus (P) and exchangeable calcium (Ca), hydrogen, manganese (Mn), magnesium (Mg), potassium (K) and sodium (Na) at A&L Great Lakes Laboratory in Indiana. To obtain CEC meq 100g soil^{-1}, the Mehlich III extractant was analyzed using an inductively coupled plasma (ICP) mass spectrometer for Ca, hydrogen, Mg, K and Na content (Mehlich, 1984). The A&L Great Lake's 1N Ammonium Acetate regression equation was applied to the measured element values and in conjunction with the soil pH the CEC meg 100g soil^{-1} was determined. To determine P Bray, the ICP analyzed the Mehlich extractant for P content and a A&L Great Lakes developed regression equation relating Mehlich colorimetric to Weak Bray colorimetric was applied. Percent soil organic matter (SOM) was determined by the loss on ignition method and using the A&L Great Lakes calibrated formula, values were converted to Walkley – Black organic matter titration values (Ben-Dor and Banin, 1989).

3.3.3 Survey and In-field Measurements

To determine farmers' incorporation of GLI technologies and their soil amendment allocation choices, all EXP trials implemented in the 2012-2013 were monitored over four growing seasons using two survey instruments (Appendix A and B). The survey instruments were used to monitor farmers plots by documenting the cultivated cropping systems and applied amendments for each year of the study. Contracted professional local enumerators along with myself administered the two survey instruments post-harvest over the course of approximately 120 days (May-August) after every two years of experimentation (2014 & 2016). During both surveys, all trials and plots were physically visited, and agronomic practices of all experimental plots were recorded. Information obtained at both time points included farmer recall of previous year 2-year cropping system history and applied amendments.

3.4 Statistical analysis:

The data analyses were conducted using SAS 9.4 PROC MIXED. Specifications of the statistical models fitted to the data varied depending on the experimental settings and are listed below for each data analysis. But, overall, the key studied groups, e.g., plot types, soil fertility levels, cropping systems and soil amendment strategies were treated as fixed factors, while individual farmer effects were regarded as a random factor.

For assessing farmers' perceptions of H and L fertility in terms of soil particle size distribution, soil TOC, soil TN, distance from main dwelling and area of plot, the statistical model included farmer defined soil fertility level (H and L) as a fixed factor; EPA and farmers nested within EPAs as random factors.

For assessing the differences in plot type (TRAD and EXP) soil particle size distribution, the statistical model included EPA and plot type as a fixed factor, section nested in EPA and farmer nested in (section X EPA) as random factors.

For assessing the edaphic property differences between EXP systems (LEG and MZ), the statistical model included EPA and system as fixed factors, section nested in EPA and farmer nested in (section X EPA) as random factors.

For assessing the differences in edaphic properties between applied soil amendment types the statistical model included amendment type as a fixed factor; EPA, section nested in EPA and farmer nested in (section X EPA) as random factors.

A chi-squared test was used to determine whether amendment allocation, species within technologies or growing season were associated with cropping systems using SAS 9.4 PROC FREQ.

The distance from the main dwelling to the H and L fertility plots as well as the distance from the main dwelling to EXP plots was determined using SAS 9.4 GOEDIST function. The distance from the main dwelling to the TRAD H and L plots was analyzed with distance as the response variable and farmer perceived fertility as the fixed factor. Random factors were EPA, farmer nested in EPA and field nested in (farmer X EPA).

The assumptions of normal distribution of the residuals and homogeneity of variances were checked in all data analyses. Potential outliers in particle size distribution data were evaluated using neighboring plots of similar topography, all other properties were evaluated by using neighboring plots with similar rotations and management in 2013 and 2014. For soil P data, the values exceeding 160 ppm were regarded as outliers and excluded from the analysis. Total inorganic nitrogen values exceeding 40 mg kg soil^{-1} were regarded as outliers; for data records with such outliers all corresponding inorganic nitrogen data were removed. Soil pH levels greater than 7 were considered outliers and eliminated.

3.5 Results:

3.5.1 Farmers' Perceptions of Soil Fertility and the Reflected Soil Fertility Gradient

To understand farmers' perceptions of soil fertility and how they relate to scientific indicators of soil fertility, we analyzed the differences between the soil properties of H and L TRAD plots. Contrary to our hypothesis that farmer defined H fertility plots will have a finer texture than L fertility plots, soil texture was not a driving factor of farmers' perceptions of soil fertility status. Instead, H and L plots differed in terms of soil chemical properties: TOC and TN. H fertility plots had significantly higher TOC and TN than L fertility plots (α=0.1 and 0.05, respectively). H fertility plots had a TOC and TN mean % value of 1.395 and 0.113, respectively, while L fertility plots had a TOC and TN mean % value of 1.259 and 0.105, respectively (Table 3.3).

Table 3.3 Soil properties, distance from main dwelling and plot area for farmer identified TRAD High and Low-fertility plots reported in means and associated standard errors. *Within each row, fertility plot types followed by the same letter are not significantly different (α=0.05), **Within each row, fertility plot types followed by the same letter are not significantly different (α=0.1).

Plot Type	High (H) Fertility		Low (L) Fertility	
Soil Property	mean	*std err*	mean	*std err*
% Sand	58.35	*1.37*	57.43	*1.54*
%Silt	29.74	*1.02*	30.75	*1.17*
% Clay	11.99	*0.97*	11.82	*1.05*
% TN	0.11^{a*}	*0*	0.10^{b}	*0*
% TOC	1.39^{a**}	*0.05*	1.26^{b}	*0.05*
pH	6.1	*0.04*	6.07	*0.04*
Distance From Main Dwelling km	0.61	*0.34*	0.57	*0.03*
Area m^2	2489.92^{a*}	*106.36*	2200.19^{b}	*99.15*

Using the same H and L TRAD plots, contrary to our hypothesis that the current soil fertility gradient would be associated with plot distance from main dwelling, we found no significant difference between H and L fertility plots in terms of distance from main dwelling. However, H fertility plots were significantly larger in total plot size area than L fertility plots, where H fertility plots' mean area was 2490 $meters^2$ and L fertility plots' mean area was 2200 $meters^2$ (Table 3.3.).

3.5.2 Soil Properties and Farmer Experimental and Traditional Plot Allocation

To understand the effects of soil properties on farmer allocation of EXP plots, we compared the differences between the EXP and TRAD plots of farmers who had both types (Table 3.4). Consistent with our hypothesis that farmers will preferentially allocate their EXP plots to coarser textured soils than their TRAD plots, we found significant differences in soil texture between farmer allocated TRAD and EXP plots. EXP trial soils had significantly higher sand content and significantly lower clay content than TRAD plots (α=0.05) Furthermore, there was no significant difference in TOC between the two plot types, yet EXP plots had significantly higher TN and significantly lower pH than TRAD plots.

Table 3.4 Effect of soil properties on farmer allocation of plot type (EXP and TRAD) reported in means and associated standard errors. * Within each row, plot types followed by the same letter are not significantly different (α=0.05).

Plot Type	EXP Plots		TRAD Plots	
Soil Properties	Mean	*std err*	Mean	*std err*
% Sand	68.4[a*]	*0.46*	54.8[b]	*1.42*
% Silt	7.88	*0.41*	8.76	*0.30*
% Clay	23.7[a]	*0.41*	36.5[b]	*1.26*
% TOC	1.27	*0.40*	1.32	*0.05*
% TN	0.13[a]	*0.003*	0.11[b]	*0.003*
pH	5.72[a]	*0.01*	6.08[b]	*0.03*

3.5.3 Soil Properties and Experimental Plot Cropping-System Allocation

To understand the effects of soil properties on farmer allocation of cropping systems within EXP plots, we compared the differences between EXP plots containing GLI technologies and those containing SOLE maize. Contrary to our hypothesis that farmers will experiment with GLI technologies on coarser textured soils, we found that overall, GLI technologies were cultivated on EXP plots with significantly lower sand and significantly higher clay content than SOLE maize EXP plots (α=0.05) (Table 3.5). EXP plots cultivated in SOLE maize had a significantly broader C:N than SOLE GLI plots (α=0.05) (Table 3.5). Additionally, SOM, CEC and % base saturation (BS) as well as TOC were all significantly higher in EXP SOLE maize plots than EXP GLI plots, yet TN was significantly greater in SOLE GLI plots than EXP SOLE maize plots (α=0.05) (Table 3.5). However, total inorganic N was significantly greater in SOLE maize plots than SOLE GLI plots, while potential mineralizable NH_4^+ was negative in value across all plots and there were no significant differences between EXP Sole maize and EXP GLI plots (α=0.05) (Table 3.5).

Table 3.5 Effect of soil properties on farmer allocation of cropping-system type within collaborative experimental plots reported in means and associated standard errors. *Systems followed by the same letter are not significantly different (α=0.05).

Cropping-system Type	Sole & Mixed Legume		Sole Maize		Mixed Maize-Legume	
Soil Property	mean	*std err*	mean	*std err*	mean	*std err*
% Sand	67.83[a*]	*0.4*	68.65[b]	*0.3*	68.68[ab]	*0.58*
% Silt	8.01	*0.12*	7.83	*0.09*	8.04	*0.21*
% Clay	24.16[a]	*0.35*	23.52[b]	*0.25*	23.29[ab]	*0.48*
% Organic Matter	2.66[a]	*0.08*	2.67[b]	*0.06*	2.69[ab]	*0.12*
CEC meq $100g^{-1}$	11.22[a]	*0.24*	11.97[b]	*0.2*	11.99[ab]	*0.49*
Ca ppm	1239.18[a]	*30.66*	1381.70[b]	*26.11*	1406.08[ab]	*68.57*
Total Inorganic N mg kg^{-1}	8.63[a]	*0.17*	10.06[b]	*0.16*	9.53[a]	*0.29*
Potential Mineralizable NH_4 mg kg^{-1}	-0.357	*0.03*	-0.362	*0.02*	-0.35	*0.04*
% TOC	1.35[a]	*0.04*	1.41[b]	*0.03*	1.43[ab]	*0.06*
% TN	0.14[a]	*0.00*	0.13[b]	*0.00*	0.13[ab]	*0.00*
C:N	9.87[a]	*0.19*	10.43[b]	*0.11*	10.95[b]	*0.35*
pH	5.68[a]	*0.01*	5.75[b]	*0.01*	5.80[b]	*0.02*
P ppm	32.56[a]	*2.66*	48.30[b]	*3.38*	46.00[ab]	*4.59*
Fe ppm	17.25[a]	*1.19*	20.28[b]	*1.01*	22.50[b]	*2.94*
K ppm	149.94	*5.34*	175.17	*5.02*	169.97	*10.9*
Mg ppm	281.67[a]	*9.55*	295.34[b]	*8.35*	274.46[ab]	*17.03*
S ppm	4.28[a]	*0.09*	4.74[b]	*0.08*	4.49[ab]	*0.25*
Zn ppm	2.37	*0.08*	2.71	*0.07*	2.36	*1.76*
Mn ppm	46.22[a]	*0.65*	48.93[b]	*0.56*	47.45[ab]	*0.1*
Cu ppm	1.13	*0.02*	1.14	*0.01*	1.25	*0.05*
B ppm	0.23	*0.01*	0.24	*0.01*	0.22	*0.01*
% Base Saturation	78.80[a]	*1.03*	80.20[b]	*1.01*	79.00[ab]	*1.7*

3.5.4 Soil Properties and Experimental Plot Soil Amendment Allocation

Our hypothesis that farmers will preferentially allocate soil amendment resources to plots that contained maize was supported by the data ($X^2_{,6}$ $p < 0.0001$). Farmers were more likely to apply fertilizer schemes that contained inorganic resources (sole inorganic and integrated) to maize systems than to legume systems and not apply any fertilizer scheme to legume systems ($X^2_{,6}$ $p < 0.0001$). Additionally, farmers were more likely to apply organic amendments to sole and mixed maize systems than to sole or mixed legume systems ($X^2_{,6}$ $p < 0.0001$). (Table 3.6). Soils without soil amendment application had significantly lower CEC and TN than those which had amendment application (α=0.05) (Table 3.6). Soils where integrated fertilizer management strategies were employed had a significantly broader C:N (α=0.05) (Table 3.6). No significant differences between soils with and without amendments were observed in terms of other soil properties (α=0.05) (Table 3.6).

Table 3.6 Collaborative experimental plot soil amendment allocation reported by frequency of soil amendment application found in each system and by soil properties associated with each system by means and associated standard errors. *Soil property followed by the same letter are not significantly different (α=0.05).

Soil Amendment Type	INORG		INTEG		NO		ORG	
System	percent	*n*	percent	*n*	percent	*n*	percent	*n*
Sole & Mixed Legume	1	*14*	0	*2*	94	*951*	4	*44*
Sole Maize	64	*409*	18	*115*	13	*84*	5	*34*
Mixed Maize - Legume	59	*196*	19	*62*	13	*44*	8	*28*
Soil Property	mean	*std err*	mean	*std err*	mean	*std err*	mean	*std err*
% Sand	69.86	*0.55*	67.86	*1.12*	68.24	*0.47*	67.36	*1.36*
% Silt	7.74	*0.19*	7.86	*0.35*	7.93	*0.13*	8.34	*0.46*
% Clay	22.4	*0.47*	24.29	*0.91*	23.82	*0.41*	24.3	*1.21*
% Organic Matter	2.56	*0.13*	2.76	*0.22*	2.66	*0.09*	2.89	*0.36*
CEC meq 100 g^{-1}	11.64[a*]	*0.44*	12.10[a]	*0.61*	11.30[b]	*0.3*	13.09[ab]	*1.11*
% TN	0.13[a]	*0*	0.15[a]	*0.01*	0.14[b]	*0*	0.15[ab]	*0.01*
% TOC	1.33	*0.06*	1.49	*0.12*	1.37	*0.05*	1.45	*0.19*
C : N	10.10[a]	*0.28*	10.20[b]	*0.43*	9.89[a]	*0.23*	9.66[a]	*0.74*

3.6 Discussion:

Although smallholder farmers do not have the ability to empirically measure soil properties, they do have environmental markers, such as crop performance, weeds species, soil color and tilth, as indicators of their on-farm soil fertility (Tittonell et al., 2008; Tittonell et al., 2005; Mowo et al., 2006). Due to the fact that the soils within many smallholder farms are highly heterogeneous in nature, these markers are very important for many of their management choices are known to be associated with soil properties that relate to soil fertility, such as: soil texture, extractable cations, TOC, soil pH, SOM, soil buffering capacity and plant available inorganic N (Lal, 2013; Snapp, 1998). The direct causes of this heterogeneity are not fully understood. Many researchers suggest that it is a result of historical and current farmer cropping system management choices. Specifically, farmers' uneven distribution and preferential allocation of labor and other limited resources results in a management gradient (Tittonel et al., 2008; Tittonell et al., 2005). That is to say that due to farmers' continuous preferential allocation of cropping system types and soil amendments, the differences in soil fertility found within farms is often increased or reinforced (Vanlauwe et al.,2002).

3.6.1 Farmers' Perceptions of Soil Fertility and the Observed Soil Fertility Gradient

In our analysis of farmer-identified high and low-fertility continuous maize plots, we determined that farmers' overall perceptions of soil fertility were associated with soil properties other than the previously reported association with soil texture (Snapp, 1998). This is consistent with the findings of others (Liu and Basso, 2017; Mairura et al., 2008). In a Malawi-wide analysis of maize productivity and soil fertility, Liu and Basso, (2017) determined that maize productivity was greater in higher fertility soils that contained greater levels of TOC. Likewise, we found that the farmer-identified high-fertility maize plots had significantly greater concentrations of both TOC and TN compared to that of their identified low-fertility maize plots – suggesting that farmers' perceptions of soil fertility in this study are in-line with scientific evidence. This is important because the soil fertility within and among Malawian smallholder farms is extremely heterogeneous and heavily influences farmers' management decisions and ultimately their crop productivity. As a result, developing relevant management recommendations within and between farms is challenging due to the variation in soil fertility and farmers' management capabilities.

The effects of farmers' soil fertility perceptions in this heterogenous system are often that of soil fertility gradients. For example, in many of the studied cropping-systems, farmers integrate livestock where the livestock is housed close to the main dwelling for security. Subsequently, due to labor and resource constraints, it has been found that farmers allocate available livestock manure and soil amendment resources to plots closer to the home. As a result, of this preferential allocation the soil fertility within farmers' landholding decreased as the distance from the main dwelling increased (Tittonell et al., 2008; Tittonell et al., 2005; Murage, 2000). Although there is limited livestock integration in Malawian farming-systems, we also found a soil fertility gradient. However, unlike the soil fertility gradients found in integrated livestock systems, we did not find differences in soil fertility between soils located closer to the main dwelling and those further away, rather we found that soil fertility within farms was greater in the larger plots than the smaller plots. These findings suggest that just as farmers preferentially allocate their available resources to meet their livelihood constraints in integrated cropping-systems, Malawian farmers in this study also preferentially allocate their available resources to fit their constraints by prioritizing their management efforts to larger plots of higher fertility.

3.6.2 The Effects of Farmers' Soil Fertility Perceptions on Collaborative Research Trial Allocation

It has become increasingly important to develop and test technologies under on-farm conditions so that research results reflect the environment for which they are developed (Falconnier et al., 2016; Vanlauwe et al., 2017; Anderson et al., 2016; Kristjanson et al., 2009; Roling, 2009; Marshall, 2001). Therefore, understanding farmers' allocation of collaborative research trials, as it pertains to farmers' perceptions of soil fertility, is an important factor not only for the research design but for the interpretation of the research findings. We compared the soil fertility status of farmers' allocated collaborative research trials to that of their traditional maize plots and we found that farmers allocate their collaborative research trials to coarser textured soils than that of their traditional maize plots. In a country-wide soil analysis, Snapp, (1998) determined that Malawian finer textured soils were associated with greater soil fertility, and therefore our findings would indicate that farmers preferentially allocate collaborative research trials to less fertile soils than their traditional maize plots.

3.6.3 The Effects of Farmers' Soil Fertility Perceptions on Cropping System Allocation

The overall soil fertility status of Malawian soils has been found to be non-conducive to the traditional maize monocropping systems (Snapp, 1998) and therefore GLI technologies have been developed as a potential solution to mitigate some of the challenges associated with low soil fertility (Vanlauwe et al., 2017). Just as it is important to understand the edaphic conditions when testing any technology on-farm, we explored the edaphic differences between farmer-designated collaborative experimental plots to their experimental maize plots allocated. We found that within farmers' experimental trials, plots allocated to maize had significantly higher total inorganic N, TOC, BS, SOM and CEC than those allocated to GLI technologies. These soil properties have been found to be associated with soil fertility, specifically soils with higher levels of these properties have been found to have greater soil fertility and resulting higher land productivity (Lal, 2013; Snapp, 1998). Therefore, are results indicate that when experimenting with GLI technologies, farmers preferentially allocate their experimental maize plots to soils of higher fertility than the research.

3.6.4 The Effects of Farmers' Soil Fertility Perceptions on Soil Amendment Allocation

As determined by Snapp et al., (1998) grain-legumes because of their nitrogenous above-ground harvest, add little if any beneficial nitrogen to the soils. To abate these challenges, they suggest that specific management strategies such as integrated soil fertility management or a legume intercropped technology are necessary. We found that experimental plots allocated to GLI technologies had lower soil fertility than those allocated to maize and that farmers' soil amendment resources were applied to nearly all experimental maize plots and little to none were applied to the plots cultivated in GLI technologies. This trend has also been observed in non-experimental farming-systems where farmers preferentially allocate their available resources foremost to cropping systems that contain maize (Mungai et al., 2016; Ortega et al., 2016; Harou et al., 2014; Derlagen and Phiri, 2012). Famers' preferential allocation of GLI technologies to soils of lower fertility without application of soil amendment strategies is concerning.

Without proper management GLI technologies can further deplete these low-fertility soils of key nutrients. Therefore, it is imperative that researchers and farmers are clear as to the management strategies necessary for the success of these heavily promoted GLI technologies in Malawi (Mungai et al., 2016; Ncube et al., 2009; Ojiem et al., 2007; Randall et al., 2006; Bezner-Kerr et al., 2007).

3.7 Conclusion:

The results of this study suggest that farmers may be using their perceptions of soil fertility as a land management strategy for increased production. Malawian farmers are food insecure and associate maize yield with their food security, this logic is not only reinforced by political and social traditions but also in terms of labor use where maize has a higher level of caloric output per unit of energy input. To further increase their food security, Malawian farmers preferentially allocate crops in which they most associate with food security (maize) to soils that they perceive to be higher in soil fertility, therefore contributing to their food security by increasing their maize yield. This preferential allocation further reinforces the soil heterogeneity found within farms by farmers preferential allocation of soil amendment resources to maize-containing cropping systems. Ultimately, and perhaps unknowingly, farmers are augmenting their higher fertility soils and further degrading their low-fertility soils – creating more intense on-farm soil fertility heterogeneity.

It is unclear as to why farmers preferentially allocate their collaborative research trials, specifically their GLI technology plots to soils of lower fertility. However, farmers are known to be risk averse because of their food insecurity and limited resources suggesting that farmers' preferential allocation of these collaborative plots to soils of lower fertility may be due to the fact that GLI technologies are promoted for their soil amelioration properties. Therefore, farmers may find value in these properties and as a result see them as a solution to increase the productivity of their low-fertility soils without sacrificing their maize yield or requiring additional resources. However, without proper management and additional inputs, these technologies are known to further degrade soils and therefore we suggest that both extension and project interventions intensify their farmer education efforts beyond that of demonstration plots and more towards the underlying agroecological principles associated with the demonstrated management recommendations. This not only has the potential to increase developed technology success, but it may also provide farmers with the knowledge necessary to increase their overall cropping system productivity based on sound scientific principles, without the assistance of researchers.

CHAPTER FOUR

MAIZE RESPONSE TO SMALLHOLDER FARMER CROPPING-SYSTEM MANAGEMENT IN CENTRAL MALAWI

Abstract:

Smallholder farmer access to and procurement of soil amendment resources and appropriate knowledge remains limited and are key contributing factors to their perpetual low soil fertility status and crop productivity. Grain-legume integration as well as crop residue incorporation have been promoted as potential farmer applicable solutions to increase overall system health and soil fertility. We used on-farm participatory action research to explore the efficacy of system grain-legume integration and the management of farmer available crop residues as a soil amelioration option in central Malawian maize-based systems. The study examined the effects of historical legume and maize intense cropping-system management and the incorporation of available crop residues as a soil amelioration strategy on subsequent maize plants in thirty on-farm trials. We found that farmers preferentially allocated maize intense cropping-systems to soils of higher fertility than that of legume intense cropping-systems and preferentially applied inorganic fertilizer nitrogen to maize cropping-systems. This and environmental factors during the growing season made understanding the role of farmer available crop residues as a soil amelioration strategy in either cropping-system not feasible in one growing season. However, we did observe that maize response to maize intense cropping-system histories was more favorable to that of legume intense cropping-systems, specifically in terms of maize grain yield. Our results suggest that this was driven by farmer past management of inorganic nitrogen fertilizers, soil organic matter content and rainfall. Foremost, this study highlights the importance of conducting research in the on-farm environment for many of the unexpected challenges we encountered are not present on research stations.

4.1 Introduction:

Increasing soil health and productivity on smallholder farms in Malawi is an urgent challenge. For the majority of Malawian farmers, access to many soil amelioration inputs, both organic and inorganic, is often not possible. However, farmers do have unlimited access to potential soil amelioration inputs such as: senesced maize stalks, ubiquitous weeds, and some leguminous residues (Sanga and Kabambe, 2014; Materechera and Mloza-Banda, 1996). Consequently, farmers' primary soil amelioration strategy, in this maize dominated system, is the incorporation of available organic post-harvest crop residues and senesced weedy biomass at time of field preparation. However, these inputs are of low quality, containing high levels of organic carbon (C) and low levels of organic nitrogen (N). This is important because plants require N in an inorganic form [ammonium (NH_4^+) and/or nitrate (NO_3^-)] for plant growth and development. Maize acquires inorganic N from the soil solution and when grown in an N deficient system, like that of Malawi, it will produce little yield of low quality (Below, 2001). This means that future farmer-available soil amendment resources are, too, of low quality – ultimately creating an iterative negative feedback cycle.

Even though crop residue incorporation is considered to be a sustainable soil amendment practice, unlike inorganic nitrogen (N) fertilizer, organic incorporated crop residue N is not immediately available to plants. It often does not release inorganic N in synchrony with subsequent crop demand and can be unpredictable due to variations in farmer management, climatic, and inherit edaphic properties (Turmel et al., 2015; Below, 2001; Drinkwater et al., 1998). Moreover, residue application rates as well as the amount of soil C and N additions from residues in corn systems of Malawi, are unknown. Crop residue incorporation is only advantageous to the farmer when the quality and application rate of residues allows for decomposition to occur and to release plant available inorganic N at the time of subsequent crop demand (N synchrony). Therefore, incorporated crop residues of low quality can have a profound effect on plant available N. Organic inputs (e.g. crop residues, manure and compost) must undergo a microbial mediated process of decomposition which ends in N assimilation. Organic N is converted by free-living soil microbes into inorganic N and is either released into the soil solution (N mineralization) or, in N deficient soils, is retained in microbial biomass (N immobilization), ultimately reducing the amount of plant available N (Bardgett, 2005; McDonagh et al., 2001; Sakala et al., 2000). The amount of N available in the soil solution is both directly and indirectly related to soil inherent physical properties, temperature, moisture, and farmer management (Lal and Stewart, 2010).

Plant decomposability is broadly determined by the amount of carbon (C) units per one unit N and is commonly referred to as the "C to N ratio" (C:N). Plant materials with a high, i.e., broad, C:N are considered to be of low quality. With broad C:N, senesced maize (70 ± 10) and ubiquitous weed (50 ± 5) residues used for ridge incorporation are of low quality (Makumba and Akinnifesi, 2008; Shepard et al., 2005; Sakala et al., 2000). However, grain-legume residue biomass is higher in N and has a more narrow C:N (Bardgett, 2005). When fresh, legume residues have C:N between 10 and 14 and are considered to be of high quality (Gentile et al., 2009; Makumba and Akinnifesi, 2008; Ibewiro et al., 2000). However, when incorporating grain-legume residues into planting ridges, Malawian farmers use senesced residues, for they often remove legume biomass at harvest, leaving it either in ridge furrows or remove it from the field where it is subject to degradation during the dry season. Consequently, at a time of incorporation, the grain-legume residues are of medium quality (C:N 24-29) (Makumba and Akinnifesi, 2008; Ibewiro et al., 2000; Sakala et al. 2000).

For N mineralization to occur, the C:N of the incorporated substrate must not be greater than 30. Large additions of low quality residues, as demonstrated by Kamanga et al., (2009) delay release of plant available N, resulting in little to no crop response (Chivenge et al., 2009). As the crop residue C:N broadens, the release timing of plant available N decreases (Mazoni, 2008; Bardgett, 2005). Incorporation of higher quality crop residue, like that of legumes, in an N deficient system, can help to achieve an optimal C:N. However, the ratio can be lowered too far and N release can occur prior to crop demand (Gentile et al., 2011, Gentile et al., 2009). Adding low quality residues simultaneously with nitrogenous high quality residues has the ability to temporarily immobilize N by broadening the C:N and releasing plant available N closer to the time of crop uptake (Dossa et al., 2009). Only when the ratio of high and low quality residues allows for decomposition to occur at a rate that releases plant available inorganic N at the time of subsequent crop demand, is crop residue C:N and mineralized N beneficial to the crop (Chirwa et al., 2006; Crews and Peoples, 2005). Crop residues are the primary soil amendment resource available to smallholder farmers and because of their low-quality nitrogen contributions are potentially immobilized or lost (Ibewiro et al., 2000).

In addition to current residue management strategies, cropping-system history also heavily influences farmer management choices, including quality and quantity of the residue available to the farmer for incorporation, and can even change soil fertility status, leaving the system not suitable for a particular crop(s) (Turmel et al., 2015; Drinkwater et al., 1998). Prior research has shown that a history of grain-legume integration in maize based systems through rotation and or intercropping, has the ability to increase crop resiliency and soil sustainability by reducing pest pressure, interrupting disease cycles and increasing total soil N through the addition of N rich below and aboveground organic inputs (Drinkwater et al., 1998; Smith et al., 2006; Ncube et al., 2007). Therefore, synchronizing nitrogen mineralization in-line with that of crop uptake through the addition of greater quantities of higher quality grain-legume residues is a viable option for resource poor Malawian farming communities.

Much research has been done to understand crop response to the addition of inorganic fertilizers to low quality residue in resource poor environments like that of Malawi (Gentile et al., 2011; Okalebo et al, 2006; Sakala et al., 2000; Palm et al., 1997). Additionally, in an attempt to improve crop response much has been done to understand the necessary ratio of low and high-quality crop residues in agroforestry cropping-systems as well as in systems containing cover crops (Ngwira, et al., 2013; Beedy et al., 2010). However, there currently are no recommendations that inform the farmer of proper residue management in either maize or legume systems as it pertains to residue incorporation (Malawi Ministry of Agriculture, 2012). Overall, farmer limitations on quality and accessibility of soil amelioration inputs are often overlooked by researchers, thus resulting in agricultural recommendations that are not well aligned with the current farmer resource base and practices. Focusing research efforts on the optimal use of the amelioration resources easily available to farmers, such as crop residues, can lead to more successful and better adopted agricultural recommendations. Specifically, the interactions between cropping-system history and the manipulation of farmer available residues, both of medium and low quality, warrants further research.

This on-farm field experiment was designed so as to address the role of farmer available residue quality and cropping-system history on the performance of maize in a diverse range of soil and environmental conditions typical to those experienced by smallholder farmers of Central Malawi. The objectives were to 1) determine the differences between farmer incorporated plant residue quantity in legume and maize intense fields, 2) analyze the role of cropping-system history and incorporated crop residue on subsequent maize plant biomass as well as 3) maize plant chlorophyll levels, as a proxy for plant N. Due to the fact that maize produces a greater quantity of above ground biomass per area than grain-legumes and that there is little farm-level competition for crop residues, we hypothesized that farmers will incorporate a greater quantity of crop residues in maize intense cropping-systems. Additionally, because legume residue biomass is known to have higher levels of N, we hypothesized that a legume intense cropping-system history will have a positive effect on subsequent harvested maize plant biomass and a positive effect on maize plant nitrogen levels.

4.2 Methods and Materials:

4.2.1 Site Description

The experiment was conducted on farmers' fields in three extension planning areas (EPA) of Central Malawi along a production potential gradient (marginal, moderate and high): 1) Golomoti, 2) Kandeu and 3) Linthipe, of Central Malawi (14.32^{0}S/34.66^{0}E, 14.65^{0}S/34.68^{0}E and 14.26^{0}S/34.10^{0}E, respectively) with elevations at 555, 904 and 1238 meters above sea level, respectively (Mungai et al., 2016). Mean annual precipitation ranges between 800-1005 mm, however during the growing season of this study (2016), there was a severe drought and rainfall events occurred on average only 35% of the growing season, ranging from 509-659 mm.

4.2.2 Experiment Description and Design

The experimental design was a three-factor completely randomized design with thirty farmer replications (ten with each EPA). The studied factors were EPA, whole and sub-plot factors in a split plot arrangement. The whole-plot factor was the previous three-year cropping history with two levels: 1) maize intense during 2013-2015 growing seasons (MI) and 2) legume intense during 2013-2015 growing seasons (LI). Cropping-systems prior to 2013 are unknown. The sub-plot factor was residue incorporation strategy with five levels reflecting type and rate of incorporated residues: 1) no residue incorporation (0), 2) pigeon pea (*Cajanus cajan*) at a rate of 4 Mg ha^{-1} (PP4), 3) pigeon pea at a rate of 2 Mg ha^{-1}, 4) maize at a rate of 4 Mg ha^{-1} (MZ4), 5) maize at a rate of 2 Mg ha^{-1}.

4.2.3 Experiment Setup

For participation in the experiment, farmers were selected using a previously obtained cropping-system histories from survey instruments obtained from Africa RISING - Malawi. Farmers who grew sole grain-legumes (sole or mixed cropping of pigeonpea, groundnut, or soyabean) (LI) and sole maize (MI) on separate plots for three consecutive growing seasons (2013-2015) were identified, the experiment was explained to them, and a permission to use land was obtained. The most homogenous 54 m^2 section of each plot (one MI plot $farmer^{-1}$ and one LI plot $farmer^{-1}$) was identified for the experiment. The MI and LI plots on each farm were marked by 1/2 m and 1 m stakes, respectively. The global positioning satellite (GPS) coordinates were then obtained using a Garmin eTrex 10 Worldwide Handheld GPS Navigator in the southeast corner of each whole-plot and recorded. Sampling and data collection activities that took place during the entire study are listed in chronological order in Table 4.1.

Table 4.1 Field activities conducted by year and month

Year	Month	Activity
2014	May - August	All plots soil sampled
2014	May - August	Survey 1 exercise
2015	March	SPAD calibration exercise
2016	November	Plot planting preparation
2016	December	Planting of trials
2016	Early March	SPAD measurements collected
2016	Mid-March through mid-April	Harvest of maize plants on plots
2016	Mid-March through mid-April	All plots soil sampled

Prior to the onset of the first seasonal rains at the end of the dry season in late November, 2015, farmer prepared planting ridges were sieved to remove any previously incorporated residue material, using a six-foot X one-foot ½ inch sieve. Six sub-plots (9 m^2) for crop residue treatments were delimitated using pegs and string. Maize residues (C:N 97) were obtained from a single farm in the Kandeu EPA and chopped prior to incorporation into 5 cm pieces. Senesced pigeon pea leaf litter (C:N 28) was obtained from a single farm's field in the Zomba EPA. Pigeon pea litter was sieved using a 2 mm soil sieve to remove any soil; all soil clods and non-pigeon pea debris were manually removed. Using SAS 9.4 PROC PLAN, sub-plot treatments were randomly assigned to each whole-plot. Residue treatments were weighed and applied at their corresponding rate. Planting ridges were then rebuilt, incorporating crop residues per farmer practice.

Immediately following the onset of the first seasonal rains and consistent with farmers' planting time in December 2016, all plots were planted in a sole maize using farmer preferred Monsanto hybrid (Deklab DKC 8033). One seed was planted in rows approximately 0.75m apart inter and 25 cm apart intra-row at a planting density of 44,444 seeds ha^{-1}. Plots were managed by researcher per farmer practice under the supervision of local lead farmers. Plots were rain fed and weeded at maize vegetative growth stages V3 and V6. Weeding technique was plant uproot and removal. Weeding at V6 additionally included rebuilding and banking of planting ridges as per farmer practice.

4.3 Data Collection and Processing:

4.3.1 Assessing Residue and Maize Biomass

After the removal of farmer incorporated crop residues, the entire sample was weighed using a handheld field scale (accurate to 0.01kg) and recorded. Due to severe drought and the onset of termite attack, plants were harvested prior to physiological maturity consistent with the time of farmer harvest (mid-March to mid-April 2015). Five random plants within the 6.25 m^2 harvest area from each sub-plot were tagged. The tagged plants were weighed using a handheld field scale (accurate to 0.01kg) and recorded. All plants within the harvest area were counted to obtain the plant population. All plants were harvested by cutting directly at the first node using bypass clippers.

The five tagged plants then underwent a partitioning destructive harvest; plants were separated into 3 sections (reproductive tissue, leaves and stalks), placed in aerated paper bags and weighed. Due to the lack of available drying resources and to avoid rotting, the partitioned tagged plants were dried in the sun until dry. Samples were then placed in a forced air oven at 70^0C for 48 hours and reweighed. Cobs were then shucked and the grain from all five plants was homogenized in a 5-liter bucket and weighed. Total grain yield ha^{-1} was obtained by using the mean dry grain weight of one plant, multiplied by the final plant population density.

4.3.2 Maize Chlorophyll Content

Using a Minolta SPAD meter, maize chlorophyll content reading was obtained from five random plants in the harvest area of each sub-plot during maize physiological stage VT, in early March of 2016. Measurements were taken from the newest fully emerged leaf (in triplicate and averaged). To determine plant TN using SPAD readings, a calibration exercise was conducted at approximately the same maize reproductive stage and time of year in 2015. The same Minolta SPAD meter was used to obtain chlorophyll readings from 1152 maize plants along a soil-input fertility gradient present in two research trials from all 4 EPAs. These trails were in a randomized complete block design. Chlorophyll readings were obtained in triplicate from the newest fully emerged maize plant leaf of eight plants from each of the six treatments in each block (n=3). Corresponding leaves were removed, and a composite plant tissue sample was collected from each treatment within each block. The samples were then dried in an oven at 70°C for fourteen days at Bunda College of Agriculture and shipped to Michigan State University for total percent C and N analysis. Samples were ground and homogenized using a Christie mill. A mass of 0.2 grams was weighed into a ceramic weigh boat in duplicate and ran with an auto sampler through the LECO ® TruMac CN combustion analyzer at the University of Michigan for total percent C and N determination.

4.3.3 Soil Sampling and Processing

Soil samples from the studied experimental sites were collected in 2014, after harvest. Soil samples were collected from each whole-plot by obtaining a soil core sample from 0-20cm depth from the center of the cropping ridge at eight random locations using a 1 inch diameter soil probe and composited. Samples were air-dried at room temperature (~26^{0}C) until constant weight was reached. Soils were then processed for soil particle size analysis using the hydrometer method (Gee and Bauder, 1986) at Lilongwe University of Agriculture and Natural Resources, Bunda Campus, Malawi (LUANAR). Biological assays using 2 M Potassium Chloride (KCL) extractions and photospectrometer were used to determine total inorganic N and potential N mineralization at Michigan State University using the Snapp Lab modified version of Drinkwater et al.,1996 total inorganic nitrogen and seven-day NH^{4+} potentially mineralizable anaerobic nitrogen assay for soil (Drinkwater et al., 1996).

In 2014, six random LI and six random MI plots were chosen from each EPA for further analysis. Soil assays for percent total organic carbon (TOC) and nitrogen (TN) were combustion analyzed using the LECO ® TruMac CN Series Macro Determinator at the University of Michigan, Blesh Lab, USA (LECO, 2014). To obtain CEC meq 100g $soil^{-1}$, the Mehlich III extractant was analyzed using an inductively coupled plasma mass spectrometer for Ca, hydrogen, Mg, K and Na content (Mehlich, 1984) at A&L Great Lakes Laboratory in Indiana. The A&L Great Lake's 1N Ammonium Acetate regression equation was applied to the measured element values and in conjunction with the soil pH the CEC meg 100g $soil^{-1}$ was determined. Percent soil organic matter (SOM) was determined by the loss on ignition method and using the A&L Great Lakes calibrated formula, values were converted to Walkley – Black organic matter titration values (Ben-Dor and Banin, 1989).

In 2016, soils were taken from the two control sub-plots of each whole-plot in the same manner as the 2014 soils were collected and handled at two time stamps (immediately prior to planting and immediately after harvest). Soils were processed for soil pH using the Australian Department of Natural Resources soil survey standard test method for 1:5 soil:water suspension (Rayment and Higginson, 1992) at Chancellor College, Zomba, Malawi (Table 4.1).

4.4 Statistical Analysis:

For assessing the differences in soil properties and in quantity of farmer incorporated residue between EPAs and the two cropping-system histories, SAS 9.4 PROC MIXED was used to fit a statistical model to include EPA and cropping-system history as fixed factors; field nested in EPA as a random factor.

For assessing the differences in final plant parameters between EPA, the two cropping-system histories and residue treatments SAS 9.4 PROC MIXED was used to fit a statistical model to include EPA, cropping-system history and residue treatments as fixed factors; field nested in EPA as a random factor

For determining the degree to which SPAD readings predict plant leaf tissue total organic N, a simple linear regression model was fitted using SAS 9.4 PROC REG to predict total organic N based on SPAD reading.

A chi-squared test of association was performed in SAS 9.4 PROC FREQ to examine the association of inorganic fertilizer application and cropping-system history.

The assumptions of normal distribution of the residuals and homogeneity of variances were checked in all data analyses.

4.5 Results:

4.5.1 Soil Characteristics

Overall, soils in this region are classified as sandy clay loams, moderately acidic, low in N, SOM and CEC. There were distinct differences in soil properties between EPAs and cropping-system histories and all soil property results can be found in Table 4.2 of this chapter. Specifically, soil pH and SOM were significantly higher in MI plots than in LI plots (α=0.05). There were also differences in nearly all measured soil properties between EPAs. In terms of soil texture, Golomoti soil a significantly higher percentage of sand than Kandeu or Linthipe (α=0.05). Likewise, Linthipe soils had a significantly higher percentage of clay than either Kandeu or Golomoti (α=0.05). Soil pH was significantly higher in Golomoti than in Kandeu and Linthipe, while soil CEC was significantly higher in Linthipe than in Kandeu and Golomoti (α=0.05). Golomoti had significantly lower SOM and TOC than Kandeu or Linthipe, while Linthipe had significantly greater SOM and TOC than Kandeu or Golomoti (α=0.05).

However, Golomoti had significantly higher potential mineralizable NH_4^+ than Kandeu and Linthipe (α=0.05).

Table 4.2 Soil properties by cropping-system history and EPA from soils sampled post-harvest 2014, reported by means and associated standard deviations. † EPA means of the same soil property with the same letters are not significantly different (α=0.05),‡ Cropping-system history means of the same soil property in the same row with the same letters are not significantly different (α=0.05), ¶ Cropping-system history means of the same soil property in the same row with the same letters are not significantly different (α=0.1).

Soil Property	Plot Type	Overall		LI		MI	
	Location	mean	*std err*	mean	*std err*	mean	*std err*
% Sand	All	64.08	*2.36*	64.77	*1.67*	63.38	*2.86*
	Golomoti	76.62[a†]	*1.30*	76.76	*1.95*	76.48	*1.23*
	Kandeu	69.94[b]	*2.54*	69.90	*3.85*	69.98	*3.08*
	Linthipe	45.68[c]	*4.21*	47.66	*2.54*	43.69	*7.93*
% Silt	All	9.60	*1.28*	8.22	*0.60*	10.97	*2.27*
	Golomoti	6.50[a]	*0.63*	6.49	*0.85*	6.51	*0.80*
	Kandeu	6.89[a]	*0.62*	6.80	*0.86*	6.98	*0.78*
	Linthipe	15.40[b]	*3.43*	11.36	*1.34*	19.44	*6.72*
% Clay	All	26.33	*1.66*	27.01	*1.65*	25.64	*1.65*
	Golomoti	16.88[a]	*1.12*	16.76	*1.36*	17.01	*1.36*
	Kandeu	23.17[b]	*2.25*	23.30	*3.07*	23.05	*3.07*
	Linthipe	38.92[c]	*2.64*	40.98	*3.64*	36.87	*3.64*
pH	All	6.01	*0.03*	5.91[a‡]	*0.05*	6.12[b]	*0.05*
	Golomoti	6.23[a]	*0.09*	6.17	*0.09*	6.29	*0.09*
	Kandeu	5.86[b]	*0.09*	5.73	*0.09*	5.99	*0.09*
	Linthipe	5.95[b]	*0.09*	5.83	*0.09*	6.07	*0.09*
CEC meq $100g^{-1}$	All	10.90	*0.62*	10.37[a¶]	*0.94*	11.40[b¶]	*0.82*
	Golomoti	8.47[a]	*0.67*	7.82	*1.15*	9.12	*0.69*
	Kandeu	10.18[a]	*0.79*	9.50	*0.87*	10.67	*1.23*
	Linthipe	14.34[b]	*0.99*	13.65	*1.60*	15.16	*1.08*

Table 4.2 (cont'd)

Soil Property	Plot Type / Location	Overall mean	Overall *std err*	LI mean	LI *std err*	MI mean	MI *std err*
SOM	All	2.52	*0.22*	2.43^{a¶}	*0.17*	2.71^{b}	*0.17*
	Golomoti	1.47^{a†}	*0.25*	1.38	*0.27*	1.55	*0.27*
	Kandeu	2.24^{b}	*0.22*	2.10	*0.23*	2.37	*0.22*
	Linthipe	4.00^{c}	*0.30*	3.80	*0.35*	4.20	*0.38*
% TOC	All	1.24	*0.09*	1.25	*0.08*	1.31	*0.09*
	Golomoti	0.92^{a}	*0.10*	0.84	*0.10*	1.01	*0.10*
	Kandeu	1.05^{b}	*0.08*	1.02	*0.08*	1.08	*0.08*
	Linthipe	1.86^{c}	*0.16*	1.88	*0.19*	1.84	*0.23*
% TN	All	0.123	*0.007*	0.128	*0.007*	0.128	*0.008*
	Golomoti	0.089	*0.007*	0.092	*0.008*	0.087	*0.008*
	Kandeu	0.134	*0.011*	0.153^{a¶}	*0.016*	0.116^{b}	*0.013*
	Linthipe	0.160	*0.011*	0.139^{a¶}	*0.014*	0.182^{b}	*0.017*
Total Inorganic N mg kg^{-1}	All	8.34	*0.54*	27.01	*1.65*	25.64	*1.65*
	Golomoti	16.88	*1.12*	16.76	*1.36*	17.01	*1.36*
	Kandeu	23.17	*2.25*	23.30	*3.07*	23.05	*3.07*
	Linthipe	38.92	*2.64*	40.98	*3.64*	36.87	*3.64*
Potential Mineralizable NH_4 mg kg^{-1}	All	-1.83	*0.78*	-1.81	*1.01*	-1.95	*1.14*
	Golomoti	1.15^{a}	*0.73*	1.83	*0.87*	0.47	*0.92*
	Kandeu	-3.53^{b}	*1.65*	-3.24	*2.33*	-3.81	*2.21*
	Linthipe	-3.26^{b}	*1.53*	-4.02	*1.72*	-2.49	*2.42*

4.5.2 Farmer Management

Consistent with our hypothesis, we found that overall the MI plots contained greater quantities of farmer incorporated biomass than the LI plots (α=0.05) (Table 4.3). The mean residue biomass in MI was equal to 868 kg ha^{-1} while in LI it was equal to 508 kg ha^{-1}. Notably, Kandeu farmers incorporated significantly higher rates of crop residue biomass than Golomoti and Linthipe (α=0.05).

Table 4.3 Maize plant parameters by cropping-system and EPA from maize plant tissue harvested between March and April of 2016 reported by means and associated standard error. † EPA means of the same plant parameter with the same letters are not significantly different (α=0.05), ‡ Cropping history means of the same soil parameter in the same row with the same letters are not significantly different (α=0.05).

	Plot Type	Overall		LI		MI	
Plant Parameter	Location	Mean	*Std Err*	Mean	*Std Err*	Mean	*Std Err*
Farmer Incorporated Residues Prior to Planting kg ha^{-1}	All	688	*99*	508^{a}	*68*	868^{b}	*182*
	Golomoti	461^{a}	*46*	477	*70*	444	*64*
	Kandeu	1349^{b}	*230*	821	*140*	1878	*376*
	Linthipe	255^{a}	*34*	227	*32*	283	*61*
Leaf % TON at Maize Stage VT	All	2.069	*0.016*	2.047	*0.023*	2.142	*0.023*
	Golomoti	2.133	*0.038*	2.117	*0.039*	2.149	*0.039*
	Kandeu	2.103	*0.038*	2.005^{a}	*0.040*	2.201^{b}	*0.039*
	Linthipe	2.047	*0.038*	2.019^{a}	*0.041*	2.075^{b}	*0.034*
Harvested Maize Biomass kg ha^{-1}	All	4278	*79*	4094^{a}	*110*	4410^{b}	*112*
	Golomoti	3720^{a}	*279*	3452	*313*	3988	*303*
	Kandeu	4708^{b}	*259*	4554	*280*	4861	*280*
	Linthipe	4329^{ab}	*248*	4275	*259*	4382	*264*
Maize Grain Yield kg ha^{-1}	All	911	*51*	708	*91*	1009	*87*
	Golomoti	505	*139*	386^{a}	*147*	624^{b}	*145*
	Kandeu	1451	*141*	1105^{a}	*150*	1797^{b}	*161*
	Linthipe	621	*143*	635	*175*	607	*143*

Participating farmers reported incorporating remaining weed biomass in their plots, where 86% of MI plots and 83% of LI plots contained weed biomass at time of residue incorporation. In addition to weed biomass, legume residues were incorporated in 41% and maize residues in 7% of LI plots. Legume residues were incorporated in 10% and maize residues in 62% of MI plots (Table 4.4). Inorganic fertilizer application was associated with cropping-system history where farmers preferentially applied inorganic fertilizer to MI plots at a greater frequency than they did to LI plots ($X^2{}_{,1}$ *p=<0.0001*). Specifically, inorganic fertilizer (NPK and/or Urea) was applied to 97% of MI plots and 7% of LI plots in the previous growing seasons.

Table 4.4 Percentage of farmers who reported incorporating residues in their fields by residue and plot type obtained from post-harvest survey in 2016.

Plot Type	Incorporated Residue Type			
	Weed %	Legume %	Maize %	None %
LI	82.8	41.4	6.9	6.9
MI	86.2	10.3	62.1	6.9

4.5.3 Maize Response

Contrary to our hypothesis, we found that LI cropping history had a negative effect on both harvested maize biomass and maize grain yield. Overall, harvested maize biomass from MI plots was significantly greater than that of LI plots (α=0.05) (Table 4.3). Specifically, in Kandeu and Golomoti, maize grain yield was significantly higher in MI plots than LI plots, while there was no significant difference between MI and LI plots in Linthipe (α=0.05) (Table 4.3).

A simple regression equation was used to predict maize leaf % total organic N (TON) based on maize SPAD chlorophyll readings (F (1,69) = 150.75. p<.0001, an R^2 of 0.6860). Predicted maize leaf % TN is equal to 0.51559 + 0.03860 (maize SPAD chlorophyll reading) when maize SPAD chlorophyll reading is measured in SPAD units from the Minolta SPAD Meter. Leaf % TON increased by 0.03860 for each SPAD unit of maize SPAD chlorophyll reading (Figure 4.1).

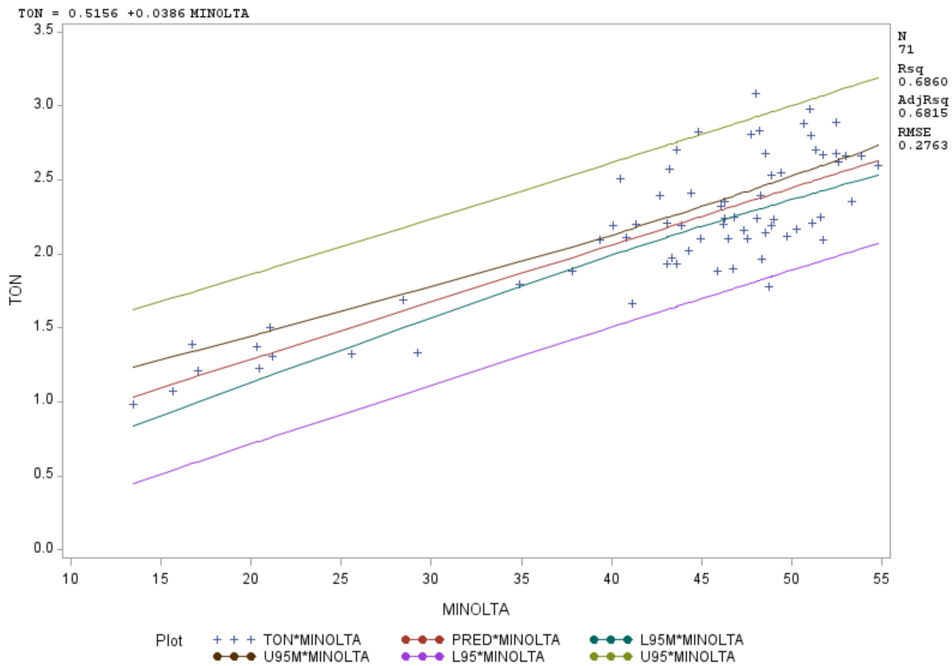

Figure 4.1 Predicted maize plant leaf %TON based off Minolta chlorophyll readings taken from 1152 maize plants along a soil-input fertility gradient present in two research trials from all 4 EPAs during March 2015.

The developed regression equation was then used to estimate % TON (Table 4.3). Contrary to our hypothesis, we found that MI plots had greater leaf % TON than LI plots, specifically in Kandeu and Linthipe, while there were no differences in maize leaf % TON between cropping-system histories in Golomoti (α=0.05) (Table 4.3). We found no maize response to any of the crop residue treatments in any of the EPAs or cropping histories.

4.6 Discussion:

4.6.1 Cropping-systems' Soil Characteristics

The continuous cultivation of maize intense systems without return of adequate nutrients, as is done in maize-dominated systems of Malawi, is known to deplete SOM levels and increase soil chemical, physical, and biological degradation (Kimetu et al., 2008; Lal, 2004; Drinkwater et al., 1998). These losses in SOM can be detrimental to the cropping-system productivity because they decreased nutrient cycling, thereby decreasing to quality and quantity of subsequent crop yields and available post-harvest crop residues (Turmel et al., 2015; Vanlauwe and Giller, 2006). In an effort to mitigate these negative effects, legume integration in smallholder farmer maize-based cropping-systems has been heavily promoted and proven to increase soil and cropping-system productivity in SSA by reducing soil C and N losses and often increasing soil SOM (Vanlauwe et al., 2017; Smith et al., 2016; Tiemann et al., 2015 Franke et al., 2014; Mhango et al., 2013, Ojiem et al., 2007; Snapp et al., 2002b; Drinkwater et al., 1998). Hence, it would be expected that LI cropping-system soils would have higher levels of SOM and TN than that of MI cropping-systems; yet, overall, we found that soils, which were historically cultivated in MI cropping-systems had significantly higher levels of SOM than soils historically cultivated in LI cropping-systems. As expected, in Kandeu we found that soils with a LI cropping-system history had significantly higher levels of TN than those cultivated in MI cropping-systems, yet unexpectedly soils in Linthipe with LI cropping-system histories had significantly lower levels of TN than those cultivated in MI cropping-systems and we found no significant differences in TN levels between the two cropping-system histories in Golomoti. It is unclear if these results reflect farmers preferential allocation of LI cropping-systems to soils of lower fertility or if it is a soil response to farmers' previous cropping-system management strategies, yet in this study the stark differences in soil fertility between the two cropping-system histories had a profound effect on the response of maize.

4.6.2 Farmer Management

Smallholder farmers in SSA, specifically in Malawi, are known to preferentially allocate available resources, e.g. soil amendments, land and labor, to cropping-systems that contain maize (Mungai et al., 2016; Ortega et al., 2016; Harou et al., 2014; Derlagen and Phiri, 2012). Plants require N in an inorganic form [ammonium (NH_4^+) and nitrate (NO_3^-)], specifically in maize-based systems, N is a key limiting nutrient and is vital for plant growth and development because it is a fundamental component of both amino and nucleic acids, which are necessary for protein development used for the biological and photosynthetic processes in maize (Below, 2001). Plants acquire N from the soil solution and therefore farmers' application of soil amendments can have a profound effect on their cropping-system productivity. Specifically, for maize, when grown in an N deficient system like that of Malawi, the lack of adequate soil amendment application will result in minimal yields of low quality (Below, 2001).

The most widely available soil amendment used by Malawian farmers is that of crop residues (Sanga and Kabambe, 2014; Materechera and Mloza-Banda, 1996). Crop residue incorporation is considered to be a sustainable soil amendment practice, yet the organic incorporated crop residue N is not immediately available to plants; often does not release inorganic N in synchrony with the crop demand and can be unpredictable due to variations in farmer management, precipitation, and inherit edaphic properties (Turmel et al., 2015; Below, 2001; Drinkwater et al., 1998). In this study, we found that farmers incorporated crop residues at a significantly higher rate to MI cropping-systems than that of LI cropping-systems. Maize crops produce residues of a greater biomass that that of legume crops, and therefore these results may suggest that farmers are not using crop residues for soil amelioration strategy but rather as a land management strategy during land preparation. However, farmers to use inorganic N fertilizer as a soil amelioration strategy. Inorganic N fertilizer is a more immediate and reliable N source available to Malawian smallholder farmers, although in limited amounts. In this study, we found that farmers applied inorganic N at a significantly greater frequency to MI plots than LI plots. These findings reinforce the previous findings of others in that farmers preferentially allocate their available soil amendment resources to MI cropping-systems. Just like that of SOM levels, farmers' soil amendment application affects both the quality and quantity of subsequent crop yields and available post-harvest crop residues (Turmel et al., 2015).

4.6.3 Maize Response

Although there is overwhelming evidence that legume integration in smallholder maize-based cropping-systems can increase cropping-system productivity, we did not find this to be true in our study (Liu and Basso, 2017; Smith et al., 2016; Snapp et al., 2002b; Drinkwater et al., 1998). Overall, we found that the maize plants cultivated on soils with MI cropping-system histories performed better than those cultivated on soils with LI cropping-system histories; however, we did not find a maize plant response to any of the crop residue treatments in any of the EPAs or cropping histories. The plants cultivated on soils previously cultivated in MI cropping-systems had a significantly higher harvested plant biomass in all EPAs as well as a higher grain yield and leaf % TON in the majority of EPAs. Our results suggest that foremost, maize plant response in this study can be explained by the stark differences in soil fertility rather than that of previous cropping-systems. These findings are consistent with that of Liu and Basso, (2017) who, in a spatial evaluation of maize yields in Malawi, found that higher maize yields were associated with soils that contained higher SOM levels.

The production potential gradient, associated with the three studied EPAs, was based on soil texture, altitude as well as historical annual rainfall and production and soil TOC, TN and SOM differences between EPAs reflected this gradient. Therefore, we expected that the higher potential location would have a better plant response than that of the moderate (Kandeu) and marginal (Golomoti) locations, but this was not reflected in our results. For example, the moderate location had the highest levels in grain yield and harvested biomass and the marginal location had the highest leaf % TON levels. These results suggest that in addition to the differences in SOM between the two cropping-system histories additional confounding factors may also have played a role in the response of maize.

During the growing season of this study (2016) there were strong El Nino conditions present; not only were the rains delayed, they were sporadic and followed by long dry spells that often lasted more than fourteen days (Malawi PDNA, 2017). It was reported by Malawi Agricultural Extension that of the three EPAs, Kandeu received the most rain and experienced the coolest temperatures, yet the rains they did receive were marginal comparative to previous years (Phiri, 2016). These conditions may explain some of the unexpected results in maize response. It has been found that inadequate soil moisture can delay nutrient cycling, specifically N mineralization (Tiemann and Billings, 2011; Bardgett, 2005). Furthermore, Tiemann and Billings (2012) found that continual wetting and drying cycles, like that of the drought of 2016, have an effect on soil N mineralization. For example, when exposed to wetting and drying cycles, soils like that of Linthipe, which typically receive adequate and consistent rainfall, often result in an increase in microbial N demand and a subsequent decrease in N mineralization; while soils like that of Golomoti that often experience these wetting and drying cycles can result in a decrease in microbial N demand and subsequent increase in N mineralization (Tiemann and Billings, 2012). We found evidence that these conditions may have had effect on maize plant response during the growing season. For example, although Golomoti soils were significantly lower in soil TN than all other EPAs, the leaf % TON was higher than that of both Kandeu and Golomoti. This suggests that either the soils in Golomoti experienced an increase in N mineralization, which resulted in the higher leaf % TON or the soils in Kandeu and Linthipe experienced a decrease in N mineralization, which was reflected in the lower levels of leaf % TON in these two locations. The unexpected poor performance of maize yield and biomass in Linthipe, in combination with the results of leaf % TON, suggest the latter.

4.7 Conclusion:

In this study, we set out to understand the potential role of farmer available crop residue resources as a soil amelioration strategy in two widely cultivated cropping-systems in a diverse range of agroecologies. However, we were unable to determine their effects on subsequent maize crop due to several confounding factors. Our results were limited foremost by farmers' preferential allocation of MI cropping-systems to soils of higher fertility as well as their preferential allocation of inorganic N resources to MI cropping-systems. Secondly, the effects of the wetting and drying cycles of the 2016 drought also played a key role in overall maize response between locations. These environmental effects and farmer management strategies in these smallholder systems are confounded and cannot be looked at separately in this study. Future studies must explore the on-farm environment for these confounding factors prior to the implementation of trials so that research time, resources and results are focused on testable hypotheses and research questions. Although the underperformance of the LI cropping-system in this study was surprising, it presents a unique opportunity to further explore the on-farm integration and management of legume cropping-systems, specifically in terms of soil amendment strategies. Lastly, we conclude that the challenges we faced in this study should not be overlooked because they are a representation of the on-farm context and are not found on research stations and therefore if agricultural research is targeted for the smallholder on-farm system, future research efforts must consider the many confounding factors we faced in this study so that the research questions can account for and be targeted towards the on-farm environment.

CHAPTER FIVE

CONCLUSION

This dissertation explored the roles that farmers' perceptions play in their integration and management of grain-legume integration technologies. We found that farmer technological adoption or adaptions are signs of farmer and researcher aligned or misaligned understandings, which presents a unique opportunity for future studies collaboration and extension. In agriculture development, researchers are presented with the amazing challenge of understanding the on-farm context so that they can develop applicable technologies that are quickly disseminated, yet often this mutual understanding is not complete and therefore technological advancements are delayed - leaving farmers with fewer options. This study highlighted the importance of understanding farmers' perceptions, choices and actions when designing, promoting and testing agricultural technologies. However, the on-farm success of technologies cannot be achieved without farmers' deeper understanding of the agroecological principles associated with the promoted technologies.

Farmers' realities have a profound effect on their perceptions as well as their decisions and are key factors in understanding farmer technological adoption or adaptation. This research demonstrated the importance of synchronizing the results of various modes of inquiry that include the needs, perceptions and preferences of the smallholder farmers as the primary stakeholder in the research. In doing so, we found that farmers' practice did not fully reflect their reported technology preferences. Further inquiry determined that livelihood indicators like that of food security and labor demands overshadowed farmers' preferences when making cropping-system choices, yet farmers do value soil fertility and technologies promoted for such. Although farmers' technology preferences and ratings could be reflective of their interest in particular technologies and therefore suggest potential technology adoption, farmers' needs and perceptions are a better determinant of their subsequent cropping-system choices. My results indicated that farmers' cropping-cropping system choices are heavily influenced by their needs and understanding of a technology's niche in their own agroecological system, regardless of its demands on available resources. For example, farmers in this study primarily cultivated sole maize, which they perceived to be the most food secure and the most labor intense of all the technologies in this study. While, additional crops are cultivated based on their ability to offset the demands of the need-filling crop as well as their ability to increase soil fertility, based on farmers' understandings and perceptions of the additional crop. On the remaining portion of their land, farmers cultivated sole legumes, which they perceived to be the least food secure, yet the least labor intense. We compared farmers' perceptions, stated preferences and practices; we determined that their practice revealed reasons behind many of their cropping-system choices. Ultimately, understanding farmers' perceptions is possibly the most useful tool in identifying both future technology uptake potential and adjustment strategies, while further aligning researcher and farmer understandings.

Farmers' perceptions of soil fertility effected their allocation of cropping-systems and collaborative trials. We found that farmer-identified high-fertility soils had significantly higher soil TOC and TN than the farmer identified low-fertility soils. Additionally, soils designated as experimental plots were less fertile than soils not designated as experimental plots, suggesting that farmers preferentially allocated their collaborative experimental plots to soils of lower fertility. The reasons for this preferential allocation are not completely clear but it may indicate that farmers are not able to risk the loss of available land for staple food production, are not willing to risk dedicating a portion of their land to unknown yields or may be a result of farmers' historical preferential allocation of maize resources to soils they perceive as having higher fertility. Moreover, farmer allocation of soil amendments was associated with cropping-system, where farmers preferentially allocated their available soil amendment resources to maize containing systems, hence systems planted on soils of higher fertility. The effects of this management were not studied in this dissertation, however if we assume that these strategies have historically been employed, then the differences observed in soil fertility may be an effect of historical cropping-system management. Foremost, this preferential allocation draws attention to the aligned and misaligned understandings between farmers and researchers and calls for deeper agroecological knowledge dissemination to the farmers. Furthermore, we determined that farmers' preferential allocation of cropping-systems based on soil properties had a confounding effect on collaborative on-farm research results. We were unable to determine the effects of crop residues managed as a soil amelioration strategy on subsequent maize crop performance. Many of the confounding factors we experienced are not present on research stations and although these factors limited our results, they highlighted the importance of on-farm research.

This dissertation uncovered opportunities and challenges associated with farmer and researcher misaligned understandings that have the potential to affect both technological research outcomes, farmer realized technological benefits and their use of promoted technologies. We provided several examples of farmer preferential allocation based off soil properties, however it remains unclear as whether or not these differences are truly a result of cropping-system preferential allocation, a function of historical cropping-system management or farmers' intentional strategy to increase soil fertility. There were differences in soil properties between cropping-systems, but there were also management differences that would, in the long-term, affect soil carbon and create stark differences in soil fertility between the soils allocated to legume intense and maize intense cropping-systems. Additionally, we have shown that, although farmers may express their preferences, their choices may not reflect those preferences because of the demands of the staple crop and farmers' perceptions of the underlying agroecological principles. Farmers' prioritize food security when making cropping system choices. Hence, farmers preferentially allocate maize cropping-systems to soils of greater fertility and available soil amendments to maize cropping-systems, while the remaining arable land and amendments are allocated to sole legume systems, for farmers perceive the latter to require the least amount of resources – offsetting the demands of maize. This reiterates the importance of considering farmers' needs associated with their staple crop when promoting cropping-system technologies in central Malawi. Ultimately, farmers associate maize with food security and therefore place its demands at the forefront of all of their cropping-system decisions. Foremost, this dissertation highlighted the value in understanding farmers' realities that is inclusive of farmers' perceptions, preferences, stated needs and, perhaps most importantly, their understanding of the underlying agroecological principles associated with the newly introduced technologies. Not only can this be an important tool used to further understand the on-farm context and adjust non-adopted technologies so that they are relevant to the intended beneficiary, it highlights the importance of educating farmers beyond that of demonstration by expanding their knowledge based on sound agroecological principles. However, synchronizing and understanding the results of these studies is limited without participatory action research and subsequent reflection, for this is an immeasurable perspective that is essential to the interpretation of the results.

APPENDICES

APPENDIX A

2014 Survey Instrument

WHO GAVE TOUR OF FARM: name:		gender:		relationship to baby farmer:		VILLAGE:
						GPS (*center of original trials*):

DRAW A MAP OF THE BABY TRIAL (*to be done by enumerator*)
(1) draw plots proportional to each other (2) label plots A, B, C or D (3) write farmer stated dimensions on each drawn plot (4) be sure to include **termite mounds (O), trees (Δ), deep areas (⁀), and any additional lanscape features like roads and homes**

LAST YEAR (year 1)		THIS YEAR (year 2) DO NOT COMPLETE THIS SECTION IF FARMER DID NOT DO YEAR TWO
LAST YEAR		THIS YEAR

EXPANDED BABY TRIAL **THIS YEAR** (year 2)

Did you plant new baby trials THIS YEAR? (*circle one*) **YES** or **NO**

If yes, what did you plant? (*list all of the crops stated by farmer*)

	CROP 1	CROP 2
CROP NAME		
WHERE PLANTED		
WHY PLANTED THERE		
SIZE OF PLOT	*portion of an acre*	*portion of an acre*

	CROP 3	CROP 4
CROP NAME		
WHERE PLANTED		
WHY PLANTED THERE		
SIZE OF PLOT (*meters*)	*portion of an acre*	*portion of an acre*

SOIL SAMPLE #1				
PLOT (circle one)	A	B	C	D
SAMPLE NUMBER				

SOIL SAMPLE #2				
PLOT (circle one)	A	B	C	D
SAMPLE NUMBER				

SOIL SAMPLE #3			
PLOT	CONT MAIZE	□ on baby	□ off baby
SAMPLE NUMBER			

1. Are you concerned about erosion? (*circle one*)		**Y**	or	**N**
2. How was rainfall this year? (*circle one*)	NOT ENOUGH	ALMOST ENOUGH	ENOUGH	TOO MUCH
3. Did you move the ridges in any field form last year to this year?		**Y**	or	**N**
4. If yes, how did you move them? (*list what the farmer states*)				
5. Why did you choose this spot for the baby trial? (*list what the farmer states*)				
6. What problems did you have in these baby trial fields? (*list what the farmer states*)				

PLOT A	FARMER DEMONSTRATES	PLOT A LAST YEAR	PLOT A THIS YEAR	
Plants	PLANTS IN PLOT		PLANTS IN PLOT	
	1	2	1	2
PLANT NAME (S)				
VARIETY				
SOURCES (S)				
AMOUNT OF SEED PLANTED IN PLOT				
NUMBER OF SEEDS PER STATION				

Soil Amendment (circle one)	COMPOST	CROP RESIDUES	FERTILIZER	MANURE	COMPOST	CROP RESIDUES	FERTILIZER	MANURE
Type								
Source(s)								
Amount added to plot								
SPACING OF ROWS	ROWS 1&2	ROWS 2&3	How did you DECIDE the spacing of the plants?		ROWS 1&2	ROWS 2&3	How did you DECIDE the spacing of the plants?	
GPS AREA of field								

A LAST YEAR

A THIS YEAR

Planting on ridge	Place the first letter of the plant on the grid where it is located on the ridge	Place the first letter of the plant on the grid where it is located on the ridge

P = pigeon pea
C = cowpea
G = grountdnut
S = soya
M = maize
OTHER:
(*code and crop*)

cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm
30																						30
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cm		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm

cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm
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cm		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm

PLOT B	FARMER DEMONSTRATES	PLOT B LAST YEAR			PLOT B THIS YEAR			
Plants	PLANTS IN PLOT				PLANTS IN PLOT			
	1		2		1		2	
PLANT NAME (S)								
VARIETY								
SOURCES (S)								
AMOUNT OF SEED PLANTED IN PLOT								
NUMBER OF SEEDS PER STATION								
Soil Amendment (*circle one*)	COMPOST	CROP RESIDUES	FERTILIZER	MANURE	COMPOST	CROP RESIDUES	FERTILIZER	MANURE
Type								
Source(s)								
Amount added to plot								
SPACING OF ROWS	ROWS 1&2	ROWS 2&3	How did you DECIDE the spacing of the plants?		ROWS 1&2	ROWS 2&3	How did you DECIDE the spacing of the plants?	
GPS AREA of field								
Planting on ridge	Place the first letter of the plant on the grid where it is located on the ridge				Place the first letter of the plant on the grid where it is located on the ridge			

P = pigeon pea
C = cowpea
G = grountdnut
S = soya
M = maize
OTHER:
(*code and crop*)

cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm
30																						30
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cm		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm

cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm
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25																						25
30																						30
cm		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm

PLOT C	FARMER DEMONSTRATES		PLOT C LAST YEAR		PLOT C THIS YEAR			
Plants	PLANTS IN PLOT				PLANTS IN PLOT			
	1		2		1		2	
PLANT NAME (S)								
VARIETY								
SOURCES (S)								
AMOUNT OF SEED PLANTED IN PLOT								
NUMBER OF SEEDS PER STATION								
Soil Amendment (circle one)	COMPOST	CROP RESIDUES	FERTILIZER	MANURE	COMPOST	CROP RESIDUES	FERTILIZER	MANURE
Type								
Source(s)								
Amount added to plot								
SPACING OF ROWS	ROWS 1&2	ROWS 2&3	How did you DECIDE the spacing of the plants?		ROWS 1&2	ROWS 2&3	How did you DECIDE the spacing of the plants?	
GPS AREA of field								
Planting on ridge	Place the first letter of the plant on the grid where it is located on the ridge				Place the first letter of the plant on the grid where it is located on the ridge			

P = pigeon pea
C = cowpea
G = grountdnut
S = soya
M = maize
OTHER:
(*code and crop*)

LAST YEAR

cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm
30																						30
25																						25
20																						20
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0																						CENTER
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25																						25
30																						30
cm		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm

THIS YEAR

cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm
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20																						20
25																						25
30																						30
cm		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	cm

PLOT D	**FARMER DEMONSTRATES** PLOT **D LAST YEAR**		PLOT **D THIS YEAR**	
Plants	**PLANTS IN PLOT**		**PLANTS IN PLOT**	
	1	**2**	**1**	**2**
PLANT NAME (S)				
VARIETY				
SOURCES (S)				
AMOUNT OF SEED PLANTED IN PLOT				
NUMBER OF SEEDS PER STATION				

D LAST YEAR

D THIS YEAR

Soil Amendment *(circle one)*	**COMPOST**	**CROP RESIDUES**	**FERTILIZER**	**MANURE**	**COMPOST**	**CROP RESIDUES**	**FERTILIZER**	**MANURE**
Type								
Source(s)								
Amount added to plot								
SPACING OF ROWS	ROWS 1&2	ROWS 2&3	**How did you DECIDE the spacing of the plants?**		ROWS 1&2	ROWS 2&3	**How did you DECIDE the spacing of the plants?**	
GPS AREA of field								

Planting on ridge

Place the first letter of the plant on the grid where it is located on the ridge

P = pigeon pea
C = cowpea
G = grountdnut
S = soya
M = maize
OTHER:
(*code and crop*)

cm	**0**	5	10	15	20	25	30	35	40	45	**50**	55	60	65	70	75	80	85	90	95	**100**	cm
30																						30
25																						25
20																						20
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10																						10
15																						15
20																						20
25																						25
30																						30
cm		5	10	15	20	25	30	35	40	45	**50**	55	60	65	70	75	80	85	90	95	**100**	cm

Place the first letter of the plant on the grid where it is located on the ridge

cm	**0**	5	10	15	20	25	30	35	40	45	**50**	55	60	65	70	75	80	85	90	95	**100**	cm
30																						30
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cm		5	10	15	20	25	30	35	40	45	**50**	55	60	65	70	75	80	85	90	95	**100**	cm

FARMER PAIR - WISE PLOT COMPARISONS

(1) Compare two technologies with each other.
(2) Circle the NUMBER of the "better" technology.
For example: if the farmer thinks 2 is better than 1, circle 2.
*NOTE: *if there are not 4 technologies, adjust the plots by "crossing - out" the missing technologies. ONLY compare the technologies present.*

	TECHNOLOGY 1	TECHNOLOGY 2	TECHNOLOGY 3	TECHNOLOGY 4
1		WHICH IS BETTER? *(circle one)* 1 2 **WHY?**	WHICH IS BETTER? *(circle one)* 1 3 **WHY?**	WHICH IS BETTER? *(circle one)* 1 4 **WHY?**
2			WHICH IS BETTER? *(circle one)* 2 3 **WHY?**	WHICH IS BETTER? *(circle one)* 2 4 **WHY?**
4				WHICH IS BETTER? *(circle one)* 3 4 **WHY?**

List additional technology comments below in this box:

APPENDIX B

2016 Survey Instrument

SOIL SAMPLE NEEDED YES NO	BABY FARMER NAME:	RESPONDENT NAME: __[1]THE BABY FARMER __[99]OTHER *(specify):*	RESPONDENT GENDER: __ M[1] __F[2]	GPS *(OF HOME)*	SOUTH ° ' ''	EAST ° ' ''	check that completed	DATE:	PW_ID
VILLAGE *(✔ one)*:			RESPONDENT RELATIONSHIP TO BABY :	GPS *(center of original baby trial)*	SOUTH ° ' ''	EAST ° ' ''	check that completed	TIME:	CONSENT *(cicle one)* YES[1] NO[2]

VILLAGE *(✔ one)*:

- LINTHIPE: __Mbidzi[1] __Mkuwazi[2]
- GOLOMOTI: __Kalumo[3] __Msamala[4] __Pitala[5] __Wilson[6]
- KANDEU: __Kampanje[7] __Katsese[8] __Gonthi[9] __Dauka[10]
- NISIPE: __Njolomole[11] __Mzililongwe[12] __Amosi[13] __Malinda[14]

RESPONDENT RELATIONSHIP TO BABY :
__THE BABY FARMER[1]
__HUSBAND[2] __WIFE[3]
__DAUGHTER[4] __SON[5]
__MOTHER[6] __FATHER[7]
__OTHER[99] *(specify):*

INTERCROPPING CONSIDERATIONS RATING EXERCISE INSTRUCTIONS:
FOR THE INTERCROPPING CONSIDERATIONS RATING, PLACETHE CONSIDERATIIONS CARD (#1) DOWN. ONE CONSIDERATION AT A TIME, HAVE THE FARMER PLACE THE CONSIDERATION CARD ALONG THE CENTER LINE OF THE CARD WHERE THEY FEEL IT FALLS AND RECORD WHERE THE CARD WAS PLACED ON THE RATING RESULTS LOCATED TO THE RIGHT OF THESE INSTRUCTIONS. AFTER YOU HAVE DONE THE EXCERCISE FOR ONE CONSIDERATION, MOVE ON TO THE NEXT CONSIDERATION. THE IDEA IS TO ASK ALL OF THE RATING QUESTIONS FOR EACH INDIVIDUAL CONSIDERATION ONE AT A TIME. ONCE YOU HAVE FINISHED ONE CONSIDERATION YOU SHOULD NOT HAVE TO PICK IT UP AGAIN.

1

IMPORTANCE OF TRAITS

CONSIDERATION	NUMBER	LETTER
PLANTING TIME		
HARVESTING		
TERMITES		
INSECTS		
WORK TOGETHER		
BRINGS MORE WEEDS		
INCREASE SOIL FERTILITY		

TECHNOLOGY RATING EXERCISE INSTRUCTIONS:
FOR THE TECHNOLOGY RATINGS, PLACE ALL PAGES (2-6) DOWN IN A LINE. ONE TECHNOLOGY AT A TIME, HAVE THE FARMER PLACE THE TECHNOLOGY CARD ALONG THE CENTER LINE OF THE CARD WHERE THEY FEEL THE TECHNOLOGY FALLS AND RECORD WHERE THE CARD WAS PLACED ON THE RATING RESULTS PAGE. AFTER YOU HAVE DONE THE EXCERCISE ON ALL 6 CARDS FOR THE ONE TECHNOLOGY, MOVE ON TO THE NEXT TECHNOLOGY. THE IDEA IS TO ASK ALL OF THE RATING QUESTIONS FOR EACH INDIVIDUAL TECHNOLOGY ONE AT A TIME. ONCE YOU HAVE FINISHED ONE TECHNOLOGY YOU SHOULD NOT HAVE TO PICK IT UP AGAIN.

2 3 4 5 6 7

FOR **LABOR RATING (CARD 3):
HAVE THE FARMER RATE EACH TECHNOLOGY ON CARD FOR LABOR THEN OUT OF THE 4 FOLLOWING CATERGORIES,
ASK THE FARMER TO CHOOSE ONE OF THE FOLLOWING WHICH INFLUENCED THEIR RATING THE MOST (✔ WHY * CHOOSE ONLY 1*):
1): PLANTING
2): WEEDING
3): HARVESTING
4): PROCESSING

PW_ID:

UNDER THE CONDITIONS OF 2013, 2014, 2015 AND 2016													GIVEN 50 KG BAG			
C2.			C3.						C4.		C5.		C6.		C7.	
YIELD OF ONE ACRE			LABOR OF ONE ACRE		WHAT ACTIVITY IS THE MOST LABOR INTENSIVE (✔ ONE)?				FOOD SECURITY OF ONE ACRE		INCOME OF ONE ACRE		STORAGE LONGEVITY OF ONE 50 KG SAC LEFT UNTOUCHED NO INSECTICIDES		NUTRITION	
					PLANTING	WEEDING	HARVESTING	PROCESSING								
TECHNOLOGY	NUMBER	LETTER	NUMBER	LETTER					NUMBER	LETTER	NUMBER	LETTER	NUMBER	LETTER	NUMBER	LETTER
MZ					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
PP					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
PPCP					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
PPGN					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
PPSOY					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
GNSOY					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZPP					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZCP					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZGN					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZSOY					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZGNSOY					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZPPGN					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								
MZPPSOY					PLANTING[1]	WEEDING[2]	HARVESTING[3]	PROCESSING[4]								

PW_ID:

HOUSEHOLD INFORMATION

B1.	IS THE HEAD OF HOUSEHOLD MALE OR FEMALE *(CIRCLE ONE)*?	M[1] F[2]
B2.	DOES THE HEAD OF HOUSEHOLD HAVE A SPOUSE *(CIRCLE ONE)*?	YES[1] NO[2] WIDOWED[3]
B3.	IF YES, IS THE SPOUSE LIVING IN THE HOUSEHOLD *(CIRCLE ONE)*?	NO SPOUSE[0] YES[1] NO[2]
B4.	IF NO, DOES THE SPOUSE CONTRIBUTE TO THE HOUSEHOLD VIA REMITTANCE, LABOR AND THE LIKE *(CIRCLE ONE)*?	NO SPOUSE[0] YES[1] NO[2] N/A[3]
B5.	HOW MANY PEOPLE IN THE FOLLOWING AGE CATEGORIES ARE SUPPORTED IN THIS HOUSEHOLD *[write total number of members (**0**,1,2,...n)]*? {INCLUDE HEAD OF HOUSEHOLD IN COUNT} ***EXCLUDE HIRED HELP***	TOTAL ☐ [a]_____ 15 YEARS AND BELOW [b]_____ BETWEEN 16 - 69 YEARS [c]_____ 70 YEARS AND ABOVE
B6.	HOW MANY ROOMS DOES THE **MAIN HOUSE** OF THE COMPOUND HAVE***(include the sitting room)***?	☐
B7.	HOW MANY DWELLINGS **BEYOND** THAT OF THE MAIN HOUSE ARE CONTAINED WITHIN THE COMPOUND *(0,1,2,...n)*? ****COUNT ALL DWELLINGS INCLUDING **TOILET**, AND **ANIMAL PENS THAT ARE A ROOM** IN THE COMPOUND*	☐
B8.	WHAT IS THE ROOF OF THE MAIN DWELLING MADE OF *(CIRCLE ONE)*?	THATCH[1] TIN[2] __[99]OTHER *(specify below)*:
B9.	WHAT MORTAR WAS USED IN THE CONSTRUCTION OF THE MAIN DWELLING *(CIRCLE ONE)*?	CEMENT[1] MUD[2] ENTIRE HOUSE MUD[3] __[99]OTHER *(specify below)*:
B10.	HOW MANY **OF THE FOLLOWING** DOES THE HOUSEHOLD OWN? *write the amount If none are owned, write **0***	☐ [A]GOATS ☐ [B]DUCKS ☐ [C]COWS ☐ [D]SWINE ☐ [E]SHEEP ☐ [F]CHICKENS ☐ [G]BICYCLES ☐ [H]OX CARTS ☐ [I]PIGEON HOUSES ☐ [J]LIVESTOCK PEN*(made of fencing)* ☐ [K]RADIOS

		(a) MAIZE	*(b)* BEAN	*(c)* COWPEA	*(d)* GROUNDNUT	*(e)* PIGEON PEA	*(f)* SOYA
B11.	BEFORE YOU RECEIVED SEED FROM AFRICA RISING IN 2013 *(first year distributed)* DID YOU GROW ANY OF THE FOLLOWING CROPS?	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]
B12.	HAVE YOU BEEN ABLE TO SELL THIS CROP SINCE YOU BEGAN WITH AR IN 2013?	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]
B13.	DO YOU CURRENTLY EAT THIS CROP IN YOUR HOUSEHOLD?	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]
B14.	IF YES, DID YOU EAT IT BEFORE YOU STARTED WITH AR IN 2013?	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]	YES[1] NO[2]

PW_ID:

WHOLE FARM MAP

ENNUMERATORS PLEASE DRAW A MAP OF THE WHOLE FARM IN REFERENCE TO THE HOSE. DRAW ALL FIELDS (NUMBERING 1,2,3...n) AND PLACE THE FOLLOWING WITHIN EACH FIELD:
ORIGINAL BABY TRIAL, YEAR 2 EXPANSION, YEAR 3 EXPANSION, YEAR 4 EXPANSION. For each field, fill out the information below the map, for year 3 & 4 expansions please fill out the information on the following page.
DRAW ANY DEFINING FEATURES E.G. MOUNTAINS, RIVERS, ROADS AND THE LIKE

MAP LABELS: *(refer to example map provided)*

HOUSE	FIELD 1	FIELD 2	FIELD ...n
ORIGINAL BABY TRIAL (OB)	**YEAR 2 EXPANSION (E2/1,2...n)**	**YEAR 3 EXPANSION (E3/1,2...n)**	**YEAR 4 EXPANSION (E4/1,2...n)**

01. HOW MANY FIELDS DOES THIS HOUSEHOLD OWN *(INCLUDING DIMBA)*? ☐
(for each field obtain the below information):

CROSS OUT THE FIELDS NOT OWNED BELOW

INFORMATION	(a) FIELD 1	(b) FIELD 2	(c) FIELD 3	(d) FIELD 4	(e) FIELD 5	(f) FIELD 6
02. FIELD NAME: *(write in)*						
03. WHAT TYPE OF FIELD IS IT (✔ONE)?	__RAINFED __DAMBO __OTHER (specify)______	__RAINFED __DAMBO __OTHER (specify)______	__RAINFED __DAMBO __OTHER (specify)______	__RAINFED __DAMBO __OTHER (specify)______	__RAINFED __DAMBO __OTHER (specify)______	__RAINFED __DAMBO __OTHER (specify)______
04. WHAT IS THE AREA OF THE FIELD? *(amount / units)*	☐ (✔ONE) __ACRES __HECTARES __M SQUARE	☐ (✔ONE) __ACRES __HECTARES __M SQUARE	☐ (✔ONE) __ACRES __HECTARES __M SQUARE	☐ (✔ONE) __ACRES __HECTARES __M SQUARE	☐ (✔ONE) __ACRES __HECTARES __M SQUARE	☐ (✔ONE) __ACRES __HECTARES __M SQUARE
05. WHAT PORTION OF THE FIELD WAS CULTIVATED THIS YEAR?	(✔ONE) __ALL __3/4 __1/2 __1/4 __NONE	(✔ONE) __ALL __3/4 __1/2 __1/4 __NONE	(✔ONE) __ALL __3/4 __1/2 __1/4 __NONE	(✔ONE) __ALL __3/4 __1/2 __1/4 __NONE	(✔ONE) __ALL __3/4 __1/2 __1/4 __NONE	(✔ONE) __ALL __3/4 __1/2 __1/4 __NONE
06. IF A PORTION WAS NOT CULTIVATE, WHY NOT? (✔all that apply)	__NO INPUTS __IMPROVE SOIL __NO LABOR __N/A __OTHER (specify)______	__NO INPUTS __IMPROVE SOIL __NO LABOR __N/A __OTHER (specify)______	__NO INPUTS __IMPROVE SOIL __NO LABOR __N/A __OTHER (specify)______	__NO INPUTS __IMPROVE SOIL __NO LABOR __N/A __OTHER (specify)______	__NO INPUTS __IMPROVE SOIL __NO LABOR __N/A __OTHER (specify)______	__NO INPUTS __IMPROVE SOIL __NO LABOR __N/A __OTHER (specify)______

NOTES:

PW_ID:

*** ENNUMERATORS: If more than 3 new plots use additional suppliment for EXPANSION

YEAR 2 (2014) EXPANSION INFO (last year) *E2*

E2/1 EXPANSION 1 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

DID YOU GROW LEGUMES ON THIS AREA OF LAND *LAST YEAR (2015)*? __YES[1] __NO[2]

DID YOU GROW LEGUMES ON THIS AREA OF LAND *THIS YEAR (2016)*? __YES[1] __NO[2]

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

E2/2 EXPANSION 2 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

DID YOU GROW LEGUMES ON THIS AREA OF LAND *LAST YEAR (2015)*? __YES[1] __NO[2]

DID YOU GROW LEGUMES ON THIS AREA OF LAND *THIS YEAR (2016)*? __YES[1] __NO[2]

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

E2/3 EXPANSION 3 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

DID YOU GROW LEGUMES ON THIS AREA OF LAND *LAST YEAR (2015)*? __YES[1] __NO[2]

DID YOU GROW LEGUMES ON THIS AREA OF LAND *THIS YEAR (2016)*? __YES[1] __NO[2]

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

YEAR 3 (2015) EXPANSION INFO (last year) *E3*

E3/1 EXPANSION 1 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

DID YOU GROW LEGUMES ON THIS AREA OF LAND *THIS YEAR (2016)*? __YES[1] __NO[2]

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

E3/2 EXPANSION 2 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

DID YOU GROW LEGUMES ON THIS AREA OF LAND *THIS YEAR (2016)*? __YES[1] __NO[2]

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

E3/3 EXPANSION 3 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

DID YOU GROW LEGUMES ON THIS AREA OF LAND *THIS YEAR (2016)*? __YES[1] __NO[2]

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

YEAR 4 (2016) EXPANSION INFO (THIS year) *E4*

E4/1 EXPANSION 1 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

E4/2 EXPANSION 2 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

E4/3 EXPANSION 3 YES[1] NO[2]	CROP 1	CROP 2
AREA: amount (✔ ONE) __ ACRES[1] __ HECTARES[2] __ M SQUARE[3]	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______	SAVED SEED? *(circle one)* YES[1] NO[2] AR? *y/n* ______
	VARIETY:	VARIETY:
	WHERE? __ NEAR BABY TRIAL[1] __ AWAY FROM BABY TRIAL[2]	

WHY GROW HERE? *(✔ONE)*: ____ ROTATION ____ AVOID LIVESTOCK ____ IMPROVE SOIL ____ LEGUMES GROW BEST ____ OTHER[99] *(specify)* ____ SOMETHING NEW ____ INTENSIFICATION

WHY DID YOU INCLUDE LEGUMES AND NOT GROW SOLE MAIZE? *(✔ONE)*: ____ IMPROVE SOIL ____ SPREAD RISK (INCOME) ____ SPREAD RISK(CLIMATE) ____ MAIZE DOES NOT GROW WELL THERE ____ OTHER[99] *(specify)* ____ NO MAIZE SEED ____ INTENSIFICATION

ENNUMERATOR: Sketch field AND plot delineating lines for YEAR 3 & 4, write system grown on designated area and label with corresponding plot letter from 2014 map. Use appropriate field letter assigned in year one from the map (A,B,…X)		**MZ**=Maize **PP**=PigeonPea **BN**=Bean **CP**=Cowpea **GN**=Groundnut **SOY**=Soya Other=write name	PW_ID:
AFRICA RISING YEAR 1 (first year seed distributed) (2013)**	**AFRICA RISING YEAR 2 (2014)**	**AFRICA RISING YEAR 3 (2015) LAST YEAR**	**AFRICA RISING YEAR 4 (2016) THIS YEAR**
1 FROM PW 2014 MAP	2 FROM PW 2014 MAP	3	4

PLOT A — YEAR 3 (2015) LAST YEAR

TECHNOLOGY(crop 1 + crop 2 + crop3):____________________

	CROP 1	CROP 2	CROP3
CROP *(✔ ONE)*	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):
VARIETY *(write in)*			
SEED SOURCE(S) *(✔ ALL THAT APPLY)*	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):
SEED/STATION *AMOUNT / LINES IN RIDGE*	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]
YIELD *AMOUNT / UNIT/TYPE*	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]

SOIL AMENDMENTS

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
COMPOST __YES[1] __NO[2] IF YES, WAS IT FULLY DECOMPOSED? __YES[1] __NO[2]		
__KITCHEN SCRAPS[1] __MAIZE RESIDUES[2] __SOYA RESIDUES[3] __GROUNDNUT RESIDUES[4] __PIGEONPEA RESIDUES[5] __COWPEA RESIDUES[6] __WEEDS[7] __ASH[8] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE /GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
ANIMAL DUNG __CATTLE[8] __GOAT[10] __CHICKEN[7] __SWINE[9] __RABBIT[11]		

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
CROP RESIDUES __YES[1] __NO[2]		
__MAIZE RESIDUES[1] __SOYA RESIDUES[2] __GROUNDNUT RESIDUES[3] __PIGEONPEA RESIDUES[4] __COWPEA RESIDUES[5] __WEEDS[6] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify): BIOMASS TRANSFER __LEGUME[1] __MAIZE[2]	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

FERTILIZER __YES[1] __NO[2]

	SOURCE	AMOUNT | UNITS
__NPK[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__UREA[2]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (own $$$)[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__OTHER *(specify)*:[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

DID YOU INCORPORATE ANY BURT MATERIAL INTO THE RIDGES? __YES[1] __NO[2]

ANIMAL DUNG __YES[1] __NO[2]

CONTENTS/TYPE	SOURCE	AMOUNT | UNITS
__CATTLE[1] __CHICKEN[2] __GOAT[3] __RABBIT[4] __SWINE[5] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

NOTES ON ADDITIONAL BORDER CROPS OR AMMENDMENTS:

PLOT A — YEAR 4 (2016) THIS YEAR — PW_ID:

TECHNOLOGY(crop 1 + crop 2 + crop3):____________________

	CROP 1	CROP 2	CROP3
CROP *(✔ ONE)*	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):
VARIETY *(write in)*			
SEED SOURCE(S) *(✔ ALL THAT APPLY)*	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):
SEED/STATION *AMOUNT / LINES IN RIDGE*	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]
YIELD *AMOUNT / UNIT/TYPE*	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]

SOIL AMENDMENTS

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
COMPOST __YES[1] __NO[2] IF YES, WAS IT FULLY DECOMPOSED? __YES[1] __NO[2]		
__KITCHEN SCRAPS[1] __MAIZE RESIDUES[2] __SOYA RESIDUES[3] __GROUNDNUT RESIDUES[4] __PIGEONPEA RESIDUES[5] __COWPEA RESIDUES[6] __WEEDS[7] __ASH[8] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE /GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
ANIMAL DUNG __CATTLE[8] __GOAT[10] __CHICKEN[7] __SWINE[9] __RABBIT[11]		

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
CROP RESIDUES __YES[1] __NO[2]		
__MAIZE RESIDUES[1] __SOYA RESIDUES[2] __GROUNDNUT RESIDUES[3] __PIGEONPEA RESIDUES[4] __COWPEA RESIDUES[5] __WEEDS[6] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify): BIOMASS TRANSFER __LEGUME[1] __MAIZE[2]	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

FERTILIZER __YES[1] __NO[2]

	SOURCE	AMOUNT | UNITS
__NPK[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__UREA[2]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (own $$$)[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__OTHER *(specify)*:[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

DID YOU INCORPERATE ANY BURT MATERIAL INTO THE RIDGES? __YES[1] __NO[2]

ANIMAL DUNG __YES[1] __NO[2]

CONTENTS/TYPE	SOURCE	AMOUNT | UNITS
__[1]CATTLE __[2]CHICKEN __[3]GOAT __[3]RABBIT __[5]SWINE __[99]OTHER *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

NOTES ON ADDITIONAL BORDER CROPS OR AMMENDMENTS:

DISTANCE BETWEEN RIDGES		
LOCATION 1	LOCATION 2	LOCATION 3
METER	METER	METER

SOIL SAMPLE

if soil sample required for this plot, remove and place in collection bag sith soil. Record information on outside of sample bag

PLOT A	PW_ID	SOIL_ID

PLOT B — YEAR 3 (2015) LAST YEAR

TECHNOLOGY(crop 1 + crop 2 + crop3):___________________________

	CROP 1	CROP 2	CROP3
CROP (✔ ONE)	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):
VARIETY *(write in)*			
SEED SOURCE(S) *(✔ ALL THAT APPLY)*	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):
SEED/STATION *AMOUNT/LINES IN RIDGE*	________ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	________ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	________ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]
YIELD *AMOUNT / UNIT/TYPE*	________ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	________ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	________ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]

SOIL AMENDMENTS

COMPOST __YES[1] __NO[2]
IF YES, WAS IT FULLY DECOMPOSED? __YES[1] __NO[2]

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
__KITCHEN SCRAPS[1] __MAIZE RESIDUES[2] __SOYA RESIDUES[3] __GROUNDNUT RESIDUES[4] __PIGEONPEA RESIDUES[5] __COWPEA RESIDUES[6] __WEEDS[7] __ASH[8] __OTHER[99] *(specify):* ANIMAL DUNG __CATTLE[8] __CHICKEN[7] __SWINE[9] __GOAT[10] __RABBIT[11]	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE /GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	☐ | __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

CROP RESIDUES __YES[1] __NO[2]

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
__MAIZE RESIDUES[1] __SOYA RESIDUES[2] __GROUNDNUT RESIDUES[3] __PIGEONPEA RESIDUES[4] __COWPEA RESIDUES[5] __WEEDS[6] __OTHER[99] *(specify):*	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify): BIOMASS TRANSFER __LEGUME[1] __MAIZE[2]	☐ | __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

FERTILIZER __YES[1] __NO[2]

	SOURCE	AMOUNT | UNITS
__NPK[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	☐ | __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__UREA[2]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (own $$$)[4] __LOCAL MARKET[5] __OTHER[99] (specify):	☐ | __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__OTHER *(specify)*:[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	☐ | __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

DID YOU INCORPORATE ANY BURT MATERIAL INTO THE RIDGES? __YES[1] __NO[2]

ANIMAL DUNG __YES[1] __NO[2]

CONTENTS/TYPE	SOURCE	AMOUNT | UNITS
__CATTLE[1] __CHICKEN[2] __GOAT[3] __RABBIT[4] __SWINE[5] __OTHER[99] *(specify):*	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	☐ | __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

NOTES ON ADDITIONAL BORDER CROPS OR AMMENDMENTS:

PLOT B — YEAR 4 (2016) THIS YEAR — PW_ID:

TECHNOLOGY(crop 1 + crop 2 + crop3):___________________________

	CROP 1	CROP 2	CROP3
CROP (✔ ONE)	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):
VARIETY *(write in)*			
SEED SOURCE(S) *(✔ ALL THAT APPLY)*	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):
SEED/STATION *AMOUNT/LINES IN RIDGE*	________ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	________ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	________ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]
YIELD *AMOUNT / UNIT/TYPE*	________ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	________ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]	________ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): | __SHELLED[1] __UNSHELLED[2]

SOIL AMENDMENTS

COMPOST __YES[1] __NO[2]
IF YES, WAS IT FULLY DECOMPOSED? __YES[1] __NO[2]

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
__KITCHEN SCRAPS[1] __MAIZE RESIDUES[2] __SOYA RESIDUES[3] __GROUNDNUT RESIDUES[4] __PIGEONPEA RESIDUES[5] __COWPEA RESIDUES[6] __WEEDS[7] __ASH[8] __OTHER[99] *(specify):* ANIMAL DUNG __CATTLE[8] __CHICKEN[7] __SWINE[9] __GOAT[10] __RABBIT[11]	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE /GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	☐ | __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

CROP RESIDUES __YES[1] __NO[2]

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
__MAIZE RESIDUES[1] __SOYA RESIDUES[2] __GROUNDNUT RESIDUES[3] __PIGEONPEA RESIDUES[4] __COWPEA RESIDUES[5] __WEEDS[6] __OTHER[99] *(specify):*	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify): BIOMASS TRANSFER __LEGUME[1] __MAIZE[2]	☐ | __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

FERTILIZER __YES[1] __NO[2]

	SOURCE	AMOUNT | UNITS
__NPK[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	☐ | __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__UREA[2]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (own $$$)[4] __LOCAL MARKET[5] __OTHER[99] (specify):	☐ | __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__OTHER *(specify)*:[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	☐ | __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

DID YOU INCORPERATE ANY BURT MATERIAL INTO THE RIDGES? __YES[1] __NO[2]

ANIMAL DUNG __YES[1] __NO[2]

CONTENTS/TYPE	SOURCE	AMOUNT | UNITS
__[1]CATTLE __[2]CHICKEN __[3]GOAT __[3]RABBIT __[5]SWINE __[99]OTHER *(specify):*	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	☐ | __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

NOTES ON ADDITIONAL BORDER CROPS OR AMMENDMENTS:

DISTANCE BETWEEN RIDGES		
LOCATION 1	LOCATION 2	LOCATION 3
METER	METER	METER

SOIL SAMPLE

if soil sample required for this plot, remove and place in collection bag sith soil. Record information on outside of sample bag

PLOT B	PW_ID	SOIL_ID

PLOT C

YEAR 3 (2015) LAST YEAR

TECHNOLOGY(crop 1 + crop 2 + crop3):____________________

	CROP 1	CROP 2	CROP3
CROP (✔ ONE)	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):
VARIETY *(write in)*			
SEED SOURCE(S) *(✔ ALL THAT APPLY)*	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):
SEED/STATION *AMOUNT/LINES IN RIDGE*	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]
YIELD *AMOUNT / UNIT/TYPE*	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): __SHELLED[1] __UNSHELLED[2]

SOIL AMENDMENTS

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
COMPOST __YES[1] __NO[2] IF YES, WAS IT FULLY DECOMPOSED? __YES[1] __NO[2]		
__KITCHEN SCRAPS[1] __MAIZE RESIDUES[2] __SOYA RESIDUES[3] __GROUNDNUT RESIDUES[4] __PIGEONPEA RESIDUES[5] __COWPEA RESIDUES[6] __WEEDS[7] __ASH[8] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE /GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
ANIMAL DUNG __CHICKEN[7] __CATTLE[8] __SWINE[9] __GOAT[10] __RABBIT[11]		

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
CROP RESIDUES __YES[1] __NO[2]		
__MAIZE RESIDUES[1] __SOYA RESIDUES[2] __GROUNDNUT RESIDUES[3] __PIGEONPEA RESIDUES[4] __COWPEA RESIDUES[5] __WEEDS[6] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify): BIOMASS TRANSFER __LEGUME[1] __MAIZE[2]	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

FERTILIZER __YES[1] __NO[2]

__NPK[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__UREA[2]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (own $$$)[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__OTHER *(specify)*:[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

DID YOU INCORPORATE ANY BURT MATERIAL INTO THE RIDGES? __YES[1] __NO[2]

ANIMAL DUNG __YES[1] __NO[2]

__CATTLE[1] __CHICKEN[2] __GOAT[3] __RABBIT[4] __SWINE[5] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

NOTES ON ADDITIONAL BORDER CROPS OR AMMENDMENTS:

PLOT C

YEAR 4 (2016) THIS YEAR

PW_ID:

TECHNOLOGY(crop 1 + crop 2 + crop3):____________________

	CROP 1	CROP 2	CROP3
CROP (✔ ONE)	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):	__MAIZE[1] __BEAN[2] __COWPEA[3] __GROUNDNUT[4] __PIGEONPEA[5] __SOYA[6] __OTHER[99] (specify):
VARIETY *(write in)*			
SEED SOURCE(S) *(✔ ALL THAT APPLY)*	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (*OWN $$$*)[4] __LOCAL MARKET[5] __SAVED FROM A PREVIOUS HARVEST[6] __AFRICA RISING[7] __OTHER[99] (specify):
SEED/STATION *AMOUNT/LINES IN RIDGE*	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]	______ __SINGLE ROW[1] __DBL ROW[2] __TRPL ROW[3]
YIELD *AMOUNT / UNIT/TYPE*	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): __SHELLED[1] __UNSHELLED[2]	______ __OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify): __SHELLED[1] __UNSHELLED[2]

SOIL AMENDMENTS

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
COMPOST __YES[1] __NO[2] IF YES, WAS IT FULLY DECOMPOSED? __YES[1] __NO[2]		
__KITCHEN SCRAPS[1] __MAIZE RESIDUES[2] __SOYA RESIDUES[3] __GROUNDNUT RESIDUES[4] __PIGEONPEA RESIDUES[5] __COWPEA RESIDUES[6] __WEEDS[7] __ASH[8] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE /GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
ANIMAL DUNG __CHICKEN[7] __CATTLE[8] __SWINE[9] __GOAT[10] __RABBIT[11]		

CONTENTS/TYPE (✔ALL THAT APPLY)	SOURCE (✔ALL THAT APPLY)	AMOUNT | UNITS
CROP RESIDUES __YES[1] __NO[2]		
__MAIZE RESIDUES[1] __SOYA RESIDUES[2] __GROUNDNUT RESIDUES[3] __PIGEONPEA RESIDUES[4] __COWPEA RESIDUES[5] __WEEDS[6] __OTHER[99] *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify): BIOMASS TRANSFER __LEGUME[1] __MAIZE[2]	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

FERTILIZER __YES[1] __NO[2]

__NPK[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__UREA[2]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER (own $$$)[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):
__OTHER *(specify)*:[1]	__FISP[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __AGRODEALER *(own $$$)*[4] __LOCAL MARKET[5] __OTHER[99] (specify):	__90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __OTHER[99] (specify):

DID YOU INCORPERATE ANY BURT MATERIAL INTO THE RIDGES? __YES[1] __NO[2]

ANIMAL DUNG __YES[1] __NO[2]

__[1]CATTLE __[2]CHICKEN __[3]GOAT __[3]RABBIT __[5]SWINE __[99]OTHER *(specify)*:	__OWN FARM/PRODUCTION[1] __BORROW/EXCHANGE/GIVEN BY OTHERS[2] __WORK FOR INPUTS[3] __OTHER[99] (specify):	__OX CART(S)[1] __90 KG SAC(S)[2] __50 KG SAC(S)[3] __KG(S)[4] __AREA OF FIELD REMAINING[5] __OTHER[99] (specify):

NOTES ON ADDITIONAL BORDER CROPS OR AMMENDMENTS:

DISTANCE BETWEEN RIDGES		
LOCATION 1	LOCATION 2	LOCATION 3
METER	METER	METER

SOIL SAMPLE

if soil sample required for this plot, remove and place in collection bag sith soil. Record information on outside of sample bag

PLOT C	PW_ID	SOIL_ID

PW_ID:

CHECK ONLY ONE CROP ON THE RIGHT WHICH YOU FEEL IS BEST FOR INTERCROPPING WITH THE CROP ON THE LEFT

1 (✔ONE) **bean**
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [99]none

1 (✔ONE) **groundnut**
- ____ [1]bean
- ____ [2]cowpea
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [99]none

1 (✔ONE) **soya**
- ____ [1]bean
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [99]none

1 (✔ONE) **cowpea**
- ____ [1]bean
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [99]none

1 (✔ONE) **pigeon pea**
- ____ [1]bean
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [5]soya
- ____ [99]none

1 (✔ONE) **maize**
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [99]none

CHECK TWO CROPS ON THE RIGHT WHICH YOU FEEL ARE BEST FOR INTERCROPPING TOGETHER WITH THE CROP ON THE LEFT AT THE SAME TIME
(if NONE was indicated for this a crop above, then please X out the crop's question below)

2 (✔TWO) **bean**
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [6]maize

2 (✔TWO) **groundnut**
- ____ [1]bean
- ____ [2]cowpea
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [6]maize

2 (✔TWO) **soya**
- ____ [1]bean
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [6]maize

2 (✔TWO) **cowpea**
- ____ [1]bean
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [5]soya
- ____ [6]maize

2 (✔TWO) **pigeon pea**
- ____ [1]bean
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [5]soya
- ____ [6]maize

2 (✔TWO) **maize**
- ____ [1]bean
- ____ [2]cowpea
- ____ [3]groundnut
- ____ [4]pigeon pea
- ____ [5]soya

ENNUMERATORS: write the crop where it is placed along the ridge

PW_ID:

FARMER DEMONSTRATED **WITHOUT** PLANTING TOOLS

PLOT **A**	YEAR 3 (2015)	**LAST YEAR**		PLOT **A**	YEAR 4 (2016)	**TH**	
	TECHNOLOGY:				TECHNOLOGY:		
MEASURED DISTANCE BETWEEN 3 PLANTS (CM)				MEASURED DISTANCE BETWEEN 3 PLANTS (CM)			
CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:

PLOT **B**	YEAR 3 (2015)	**LAST YEAR**		PLOT **B**	YEAR 4 (2016)	**THIS YEAR**	
	TECHNOLOGY:				TECHNOLOGY:		
MEASURED DISTANCE BETWEEN 3 PLANTS (CM)				MEASURED DISTANCE BETWEEN 3 PLANTS (CM)			
CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:

PLOT **C**	YEAR 3 (2015)	**LAST YEAR**		PLOT **C**	YEAR 4 (2016)	**THIS YEAR**	
	TECHNOLOGY:				TECHNOLOGY:		
MEASURED DISTANCE BETWEEN 3 PLANTS (CM)				MEASURED DISTANCE BETWEEN 3 PLANTS (CM)			
CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:

ENNUMERATORS: Transfer crops from previous page for each year and field and then remeasure farmer recollected

FARMER DEMONSTRATED **USING** PLANTING TOOLS

PLOT **A**	YEAR 3 (2015)	**LAST YEAR**		PLOT **A**	YEAR 4 (2016)	**THIS YEAR**	
	TECHNOLOGY:				TECHNOLOGY:		
MEASURED DISTANCE BETWEEN 3 PLANTS (CM)				MEASURED DISTANCE BETWEEN 3 PLANTS (CM)			
CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:

PLOT **B**	YEAR 3 (2015)	**LAST YEAR**		PLOT **B**	YEAR 4 (2016)	**THIS YEAR**	
	TECHNOLOGY:				TECHNOLOGY:		
MEASURED DISTANCE BETWEEN 3 PLANTS (CM)				MEASURED DISTANCE BETWEEN 3 PLANTS (CM)			
CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:

PLOT **C**	YEAR 3 (2015)	**LAST YEAR**		PLOT **C**	YEAR 4 (2016)	**THIS YEAR**	
	TECHNOLOGY:				TECHNOLOGY:		
MEASURED DISTANCE BETWEEN 3 PLANTS (CM)				MEASURED DISTANCE BETWEEN 3 PLANTS (CM)			
CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 1:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 2:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:
CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:	CROP 3:	PLANT 1-2:	PLANT 2-3:	PLANT 3-4:

ENNUMRATORS: AFTER COMPARISIONS ARE COMPLETE, PLEASE TALLY UP THE TOTAL NUMBER OF TECHNOLOGIES REPRESENTED IN THE WRITTEN BOXES PER SYSTEM

PW_ID:

CIRCLE WHICH IS BEST *(WRITE ONLY ONE OF THE TWO COMPARISIONS)*

MZ=Maize PP=PigeonPea BN=Bean CP=Cowpea GN=Groundnut SOY=Soya

	BEAN					COWPEA				GROUNDNUT			PIGEON PEA		SOY
"between the two SOLE crops"=>	BN	BN	BN	BN	BN	CP	CP	CP	CP	GN	GN	GN	PP	PP	SOY
WHICH IS BEST?	CP	GN	PP	SOY	MZ	GN	PP	SOY	MZ	PP	SOY	MZ	SOY	MZ	MZ

TOTALS / SOLE SYSTEMS

BN	CP	GN	PP	SOY	MZ

MZ=Maize MZBN=Maize+Bean MZCP=Maize+Cowpea MZGN=Maize+Groundnut MZPP=Maize+PigeonPea MZSOY=Maize+Soya

	MZ+BN &					MZ+CP &				MZ+GN &			MZ+PP &		MZ+SOY &
"between the two INTERCROPS"=>	MZ + BN	MZ + BN	MZ + BN	MZ + BN	MZ + BN	MZ + CP	MZ + CP	MZ + CP	MZ + CP	MZ + GN	MZ + GN	MZ + GN	MZ + PP	MZ + PP	MZ + SOY
WHICH IS BEST?	MZ + CP	MZ + GN	MZ + PP	MZ + SOY	MZ	MZ + GN	MZ + PP	MZ + SOY	MZ	MZ + PP	MZ + SOY	MZ	MZ + SOY	MZ	MZ

TOTALS / MZ-LEG INTRCP SYSTEMS

MZBN	MZCP	MZGN	MZPP	MZSOY	MZ

MZ=Maize GNSOY=Groundnut+Soya PPGN=PigeonPea+Groundnut PPSOY=PigeonPea+Soya
MZGNSOY=Maize+Groundnut+Soya MZPPGN=Maize+PigeonPea+Groundnut MZPPSOY=Maize+PigeonPea+Soya

	GN+SOY &			PP+GN &		PP+ SOY &		MZ+GN+SOY &			MZ+PP+GN &		MZ+PP+ SOY &
"between the two INTERCROPS"=>	GN + SOY	GN + SOY	GN + SOY	PP + GN	PP + GN	PP + SOY		MZ+GN + SOY	MZ+GN + SOY	MZ+GN + SOY	MZ+PP + GN	MZ+PP + GN	MZ+PP + SOY
WHICH IS BEST?	PP + GN	PP + SOY	MZ	PP + SOY	MZ	MZ		MZ+PP + GN	MZ+PP + SOY	MZ	MZ+PP + SOY	MZ	MZ

LEG-LEG INTERCROP

GNSOY	PPGN	PPSOY	MZ

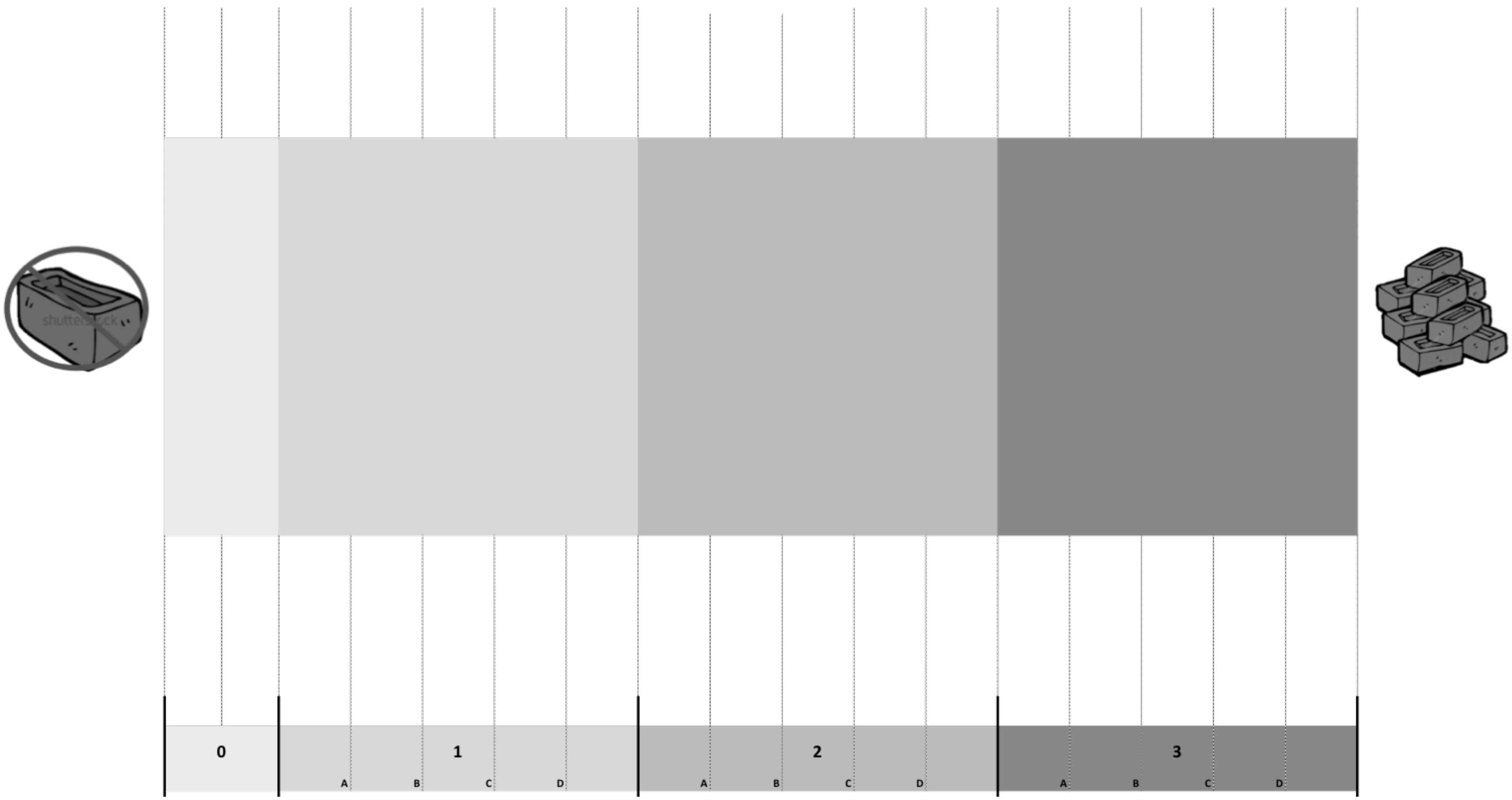
TOTALS MAIZE-LEG-LEG INTERCROP

MZGNSOY	MZPPGN	MZPPSOY	MZ

ENNUMERATORS: please check off the technologies grown in the past two years from the below list.
If a technology grown is not in the list below, please compare those not included to SOLE Maize to the right.
If all TECHNOLOGIES are represented, proceed to the INVENTORY on VERY RIGHT BOTTOM of this page.

SOLE SYSTEM	MAIZE-LEGUME INTERCROPPED	LEGUME-LEGUME INTERCROPPED	MAIZE LEGUME-LEGUME INTERCROP
___ MZ	___ MZ+BN	___ GN+SOY	___ MZ+GN+SOY
___ BN	___ MZ+CP	___ PP+GN	___ MZ+PP+GN
___ CP	___ MZ+GN	___ PP+SOY	___ MZ+PP+SOY
___ GN	___ MZ+PP		
___ PP	___ MZ+SOY		
___ SOY			

CROP NOT LISTED TO THE LEFT:	SOLE MZ	WHICH IS BEST?
TECHNOLOGY:	MZ	
TECHNOLOGY:	MZ	
TECHNOLOGY:	MZ	


0
1
A B C D
2
A B C D
3
A B C D

WORKS CITED

WORKS CITED

Ajayi, O. C., F.K. Akinnifesi, G. Sileshi and W. Kanjipite. 2009. Labor inputs and financial profitability of conventional and agroforestry-based soil fertility management practices in Zambia. Agrekon 48: 276-292.

Ajayi, O. C., F. K. Akinnifesi, G. Sileshi and S. Chakeredza. 2007. Adoption of renewable soil fertility replenishment technologies in the southern Africa region: Lessons learnt and the way forward. Natural Resources Forum 31:306-317.

Alene, A. D. and O. Coulibaly. 2009. The impact of agricultural research on productivity and poverty in sub-Saharan Africa. Food Policy. 35:198-209.

Anderson, W., C. Johansen and K. H. M. Siddique. 2016. Addressing the yield gap in rainfed crops: a review. Agron. Sustain. Dev. 36:19-8.

Anyanzwa, H., J. R. Okalebo, C. O. Othieno, A. Baltiono, B.S. Waswa and J. Kihara. 2010. Effects of conservation tillage, crop residue and cropping-systems on changes in soil organic matter and maize-legume production: a case study in Teso District. Nutrient Cycling and Agroecosystems. 88:39-47.

Bardgett, R. 2005. The Biology of Soil. Pg.63. Oxford University Press. New York, USA.

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

Beedy, T.L., S.S. Snapp, F.K. Akinnifesi and G.W. Sileshi. 2010. Impact of Gliricidia sepium intercropping on soil organic matter fractions in a maize-based cropping-system. Agriculture, Ecosystems & Environment. 138: 139-146.

Below, F. E. 2001. Nitrogen Metabolism and Crop Productivity. *In* Handbook of Plant and Crop Physiology. Pgs. 385-405. Ed. M. Pessarakli. Marcel Dekker, Inc. New York, USA.

Ben-Dor, E. and A Banin. 1989. Determination of organic matter content in arid-zone soils using a simple "loss-on-ignition" method. Communications in Soil Sceince and Plant Analysis. 20:1675-1695.

Bezner-Kerr, R., S. Snapp, M. Chirwa, L. Shumba and R. Msachi. 2007. Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. Experimental Agriculture. 43:437-453.

BMGF Bill and Melinda Gates Foundation. 2010. Agricultural Development Outcome Indicators: Initive and Sub-initive Progress Indicators % Pyramid of Outcome Indicators, BMGF.

Bolliger, A., J. Magid, T. J. C. Amado, F. S.Neto, M. F. S. Ribeiro, A. Calegari, R. Ralisch and A. de Neergaard. 2006. Taking Stock of the Brazilian ""Zero-Till Revolution"": A Review of Landmark Research and Farmers' Practice. Advances in Agronomy 91: 47-110.

Brooks, S. 2014. Enabling adaptation? Lessons from the new 'Green Revolution' in Malawi and Kenya. Climate Change. 122:15-26.

Carberry, P. S. 2001. Can science rigor and industry relevance both be achievable in participatory action research? Agricultural Science. 14, 25-31.

Carberry, P.S., W. Liang, S. Twomlow, D. P. Holzworth, J. P. Dimes, T. McClelland, N. I. Huth, F. Chen, Z. Hochman and B. A. Keating. 2013. Scope for improved eco-efficiency varies among diverse cropping-systems. PNAS. 110:8381-8386.

Chikowo, R. S. Zingore, S. Snapp, and A. Johnston. 2014. Farm typologies, soil fertility variability and nutrient management in smallholder farming in Sub-Saharan Africa. Nutrient Cycling in Agroecosystems 100:1-18.

Chirwa, P. W., C. R. Black, C. K. Ong and J. Maghembe. 2006. Nitrogen Dynamics in cropping-systems in Malawi containing Gliricidia sepium, pigeonoea and maize. Agroforestry Systems. 67:93-106.

Chivenge, P., B. Vanlauwe, R. Gentile and J. Six. 2011. Organic resource quality influences short-term aggregate dynamics and soil organic carbon an nitrogen accumulation. Soil iology & Biochemistry. 43: 657-666.

Chivenge, P., B. Vanlauwe, R. Gentile, H. Wangechi, D. Mugendi, C. van Kessel, and J. Six. 2009. Organic and Mineral Input Management to Enhance Crop Productivity in Central Kenya. Agronomy Journal 101(5):1267-1275.

Crews, T. E. and M. B. Peoples. 2005. Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer-based agroecosystems? A review. Nutrient Cycling in Agroecosystems. 72:101-120.

Derlagen, C. and H. Phiri. 2012. Analysis of incentives and disincentives for groundnuts in Malawi. Technical notes series, MAFAP, FAO, Rome. http://www.fao.org/3/a-at565e.pdf Accessed 21 December 2017.

Dossa, E.L., M. Khouma, I. Diedhiou, M. Sene, F. Kizito, A.N. Badiane, S.A.N. Samba, and R.P. Dick. 2009. Carbon, nitrogen and phosphorus mineralization potential of semiarid Sahelian soils amended with native shrub residues. Geoderma 148:251-260.

Drinkwater, L. E., P Wagoner and M. Sarrantonio. 1998. Legume-based cropping-systems have reduced carbon and nitrogen losses. Letter to Nature. 396:262-264.

Drinkwater, L. E., C. A. Cambardella, J. D. Reeder and C. W. Rice. 1996. Potentially Mineralizable Nitrogen as an Indicator of Biologically Active Soil Nitrogen. In Methods For Assessing Soil Quality. P. 217-229.

Ellis, F., M. Kutengule and A. Nyasulu. 2003. Livelihoods and Rural Poverty Reduction in Malawi. World Development. 31: 1495-1510.

Falconnier, G. N., K. Descheemaeker, T. A. Van Mourik and K. E. Giller. 2016. Unravelling the causes of variability in crop yields and treatment responses for better tailoring of options for sustainable intensification in southern Mali. Field Crops Research. 187:113-126.

FAO. 2016a. Global Information and Early Warning System on Food and Agriculture. 22 September 2016 http://www.fao.org/giews/countrybrief/country.jsp?code=MWI Accessed 29 September 2016.

FAO. 2016b. Adapting to Climate Change in Smallholder Agriculture. In The State of Food and Agriculture: Climate Change, Agriculture and Food Security. Pg 57. Food and Agriculture Organization of the United Nations. Rome, Italy.

Fisher, M. and S. Snapp. 2014. Smallholder farmers' perceptions of drought risk and adoption of modern maize in southern Malawi. Experimental Agriculture. 50: 533-548.

Franke, A. C., G. J. van den Brand and K. E. Giller. 2014. Which farmers benefit most from sustainable intensification? An ex-ante assessment of expanding grain-legume production in Malawi. European Journal of Agronomy. 58:28-38.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. p. 383–411. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Gentile, R., B. Vanlauwe, P. Chivenge, and J. Six. 2011. Trade- offs between short- and long- term effects of residue quality on soil C and N dynamics. Plant Soil 338:159-169.

Gentile R., B. Vanlauwe, P C. van Kessel and J. Six. 2009. Managing N availability and losses by combining fertilizer-N with different quality residues in Kenya. Agriculture, Ecosystems and Environment. 131:308-314.

German, L., J. Mowo and M. Kingamkono. 2006. A methodology for tracking the "fate" of technological interventions in agriculture. Agriculture and Human Values. 23:353-369.

Giller, K. E., E. Witter, M. Corbeeks and P, Tittonell. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research. 114:23-34.

Greenwood, D. J., W. F. Whyte and I. Harkavy. 1993. Participatory action research as a process and as a goal. Human Relations. 46: 175-192.

Goldman, A. 1995. Threats to Sustainability in African Agriculture: Searching for Appropriate Paradigms. Human Ecology. 23:291-334.

Gowing, J. W. and M. Palmer. 2008. Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. Soil Use and Management. 24: 92-99.

Green, E. 2007. Modern Agricultural History in Malawi: Perspectives on Policy-Choice Explanations. African Studies Review. 50:115-133.

Guerena, D. T., J. Kimetu, S. Riha, H. Neufeldt and J. Lehmann. 2016. Maize productivity dynamics in response to mineral nutrient additions and legacy organic soil inputs of contrasting quality. Field Crops Research. 188:113-120.

Harou, A., Y. Y. Liu, C. B. Barrett, and L. Z. You. 2014. Variable returns to fertilizer use and its relationship to poverty: experimental and simulation evidence from Malawi. IFPRI – Discussion Papers 1373:vi-27.

Harrigan, J. 2003. U-Turns and Full Circles: Two Decades of Agricultural Reform in Malawi 1981-2000. World Development. 31: 547-863.

Hockett, M., A. Smith, S. Snapp, R. Chikowo and R. Richardson. 2014. Africa RISING Farming-systems Analysis Baseline Report. Michigan State University, USA.

Ibewiro, B., N. Sanginga, B. Vanlauwe and R. Merckz. 2000. Nitrogen contributions from decomposing cover crop residues to maize in a tropical derived savanna. Nutrient Cycling and Agroecosystems 57:131-140.

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

Kamanga, B. C. G., G. Y. Kanyama-Phiri, S. R. Waddington, C. J. M Almekinders and K. E. Giller. 2014. The evaluation and adoption of annual legumes by smallholder maize farmers for soil fertility maintenance and food diversity in central Malawi. Food Security. 6:45-59.

Kamanga, B. C. G., S. R. Waddington, M. J. Robertson, and K. E Giller, 2010. Risk Analysis of Maize – Legume Crop Combinations with Smallholder Farmers Varying in Resource Endowment in Central Malawi. Experimental Agriculture 48:1-21.

Kanyama-Phiri, G., S. Snapp and S. Minae. 1998. Partnership with Malawian farmers to develop organic matter technologies. Outlook in Agriculture, 27:167-175.

Kassie, M., H. Teklewold, M. Jaleta, P. Marenya and O. Erenstien. 2015. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. Land Use Policy. 42: 400-411.

Kimetu, J. M., J. Lehmann, S. O. Ngoze, D. N. Mugendi, J. M. Kinyangi, S. Riha, L. Verchot, J. W. Recha and A. N. Pell. 2008. Reversibility of Soil Productivity Decline with Organic Matter of Differeing Quality Along a Degradation Gradient. Ecosystems. 11:726.

Kiptot, E., P. Hebinick, S. Franzel and P. Richards. 2007. Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. Agricultural Systems. 94:509-519.

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. 30:470-484.

Kristjanson, P., R. S. Reis, N. Dickson, W. C. Clark, D. Romney, R, Puskur, S. MacMillan and D. Grace. 2009. Linking international agricultural research knowledge with action for sustainable development. PNAS. 106:5047-5052.

Kwesiga, F. K. Akinnifesi, P.L Mafongoya, M. H. McDermott, and A Agumya. 2003. Agroforestry research and development in southern Africa during the 1990s: Review and challenges ahead. Agroforestry Systems 59:173-186.

Lal, R. 2013. Principles of Soil Management. Pages 1-18 in R. Lal and B. A. Stewart editors. Principles of Sustainable Soil Management in Agroecosystems. CRC Press, Boca Raton, FL, USA.

Lal, R., and B. A. Stewart. 2010. Preface. Pages vii-viii in R. Lal and B. A. Stewart editors. Food Security and Soil Quality. CRC Press, Boca Raton, FL, USA.

Lal, R. 2004. Soil Carbon Sequestration Impacts on Global Change and Food Security. Sience. 304: 1623-1627.

Laird, D. A. and C. W. Chang. 2013. Long-term impacts of residue harvesting on soil quality. Soil & Tillage Research. 134:33-40.

Lamb, J. N., K. M Moore, J. Norton, E. C. Omondi, R. Laker-Ojok, D. N. Sikuku, A. Odera and J. Odera. A social networks approach for strengthening participation in technology innovation: lessons learnt from the Mount Elgon region of Kenya and Uganda. International Journal of Agricultural Sustainability. 14:1, 65-68.

LECO Corporation. 2014. TruMac® Series Macro Determinator. Form No. 209-203. 2014. https://www.leco.com/analytical-library-cat?task=document.viewdoc&id=11 Accessed 15 August 2014.

Liu, L. and B. Basso. 2017. Spatial evaluation of maize yield in Malawi. Agricultural Systems. 157: 185.192.

Mairura, F. S., D. N. Mugendi, J. I. Mwanje, J. J. Ramisch, P. K. Mbugua and J. N. Chianu. 2008. Scientific evaluation of smallholder land use knowledge in Central Kenya. Land Degradation & Development. 19:77-90.

Makumba, W. and F. K. Akinnifesi. 2008. Mineralization and N-use efficiency of tree legume prunings from fertilizer tree systems and low quality crop residues in Malawi. African Journal of Biotechnology. 7: 3266-3274.

Malawi Ministry of Agriculture. 2012. Guide to Agricultural Production and Natural Resource Management. Agricultural Communication Branch, Department of Agricultural Extension Services Ministry of Agriculture and Food Security. Lilongwe, Malawi.

Mapila, M. A.T. J., J. Yauney, P. Thangata, K. Droppelman and J. Mazunda. 2016. Who Talks to Whom in Malawi's agricultural Research Information Network?. The Journal of Agricultural Research and Extension. 22: 7-23.

Marshall, J., 2001. "Self-reflective Inquiry Practices" in Handbook of Action Research eds. Reason, P. and H. Brandbury. Sage Publications. London, UK.

Materechera, S. A. and H. R. Mloza-Banda. 1996. Soil penetration resistance, root growth and yield of maize as influenced by tillage system on ridges in Malawi. Soil & Tillage Research. 41:13-24.

Mazoni, S., R. B. Jackson, J. A. Trofymow and A. Porporato. 2008. The global stoichiometry of litter nitrogen mineralization. Science. 321:684-686.

McDonagh, J. F., T. B. Thomsen and J. Magid. 2001. Soil organic matter decline and compositional change associated with cereal cropping in Southern Tanzania. Land Degradation & Development. 2001. 12:13-26.

McCown, R. L. 2001. Learning to bridge the gap between science based decision support and the practice of farming: evolution in paradigms of model-based research and intervention from design to diologue. Austrailian Journal of Agricultural Research. 52, 549-571.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis. 15:12, 1409-1416.

Meijer, S.S., D. Catacutan, O.C. Ajayi, G. W. Sileshi and M. Nieuwenhuis. 2015. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. International Journal of Agricultural Sustainability. 13: 40-54.

Mhango, W. G., S. S. Snapp and G. Y. K. Phiri. 2013. Opportunities and constraints to legume diversification for sustainable maize production on smallholder farms in Malawi. Renewable Agriculture and Food Systems. 28: 234-244.

Mowo, J. G., B. H. Janssen, O. Oenema, L. A. German. J. P. Mrema and R. S. Shemdoe. 2006. Soil fertility evaluation and management by smallholder farmers in northern Tanzania. Agriculture, Ecosystems & Environmant. 116:47-59.

Mponela, P., L. Tamene, G. Ndengu, R. Magreta, J. Kihara and N. Mango. 2016. Determinants of integrated soil fertility management technologies adoption by smallholder farmers in the Chinyanja Triangle of Southern Malawi. Land Use Policy 59: 38-48.

Mulwafu. W. O., 2011. Conservation Song. Pgs 216-219. The White House Press. Cambridge, UK.

Mungai, L., S.S. Snapp, J.P. Messina, R. Chikowo, A. Smith, E. Anders, R. Richardson and G. Li. 2016. Smallholder farms and the potential for sustainable intensification. Frontiers in Plant Science. 7, 1720. DOI:10.3389/fpls.2016.01729

Murage, E. W., N. K. Karanja, P. C. Smithson and P. L. Woomer. 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. Agriculture, Ecosystems and Environment. 79:1-8.

Ncube, B., S. J. Twomlow, M. T. van Wijk, J. P. Dimes and K. E. Giller. 2007. Productivity and residual benefits of grain-legumes to sorghum under semi-arid conditions in southwestern Zimbabwe. Plant Soil. 299:1-15.

Ngwira, A. R., J. B. Aune, and C. Thierfelder. 2014. On-farm evaluation of the effects of the principles and components of conservation agriculture on maize yield and weed biomass in Malawi. Experimental Agriculture 50:591-610.

Ngwira, A. R., M. Nyirenda, and D. Taylor. 2013. Toward Sustainable Agriculture: An Evaluation of Compost and Inorganic Fertilizer on Soil Nutrient Status and Productivity of Three Maize Varieties Across Multiple Sites in Malawi. Agroecology and Sustainable Food Systems 37:859-881.

Ogoke, I . J., I. I. Ibeawuchi, A. A. Ngwuta, C. T. Tom and E. U. Onweremadu. 2009. Legumes in the Cropping-systems of Southeastern Nigeria. Journal of Sustainable Agriculture. 33:8223-834.

Ojiem, J. O., B. Vanlauwe, N. de Ridder and K. E. Giller. 2007. Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms. Plant and Soil. 292:119-135.

Okalebo, J.R., C.O. Othieno. P. L Woomer, N.K. Karanja, J.R.M. Semoka, M.A. Bekunda, D.N. Mugendi, R.M. Muasya, A. Bationo and E, J. Mukhwana. 2006. Available technologies to replenish soil fertility in East Africa. Nutrient Cycling in Agroecosystems. 79:153-170.

Orr, A. 2003. Integrated pest management for resource-poor African farmers: Is the emperor naked?. World Development. 31:831-845.

Ortega, D. L., K. B. Waldman, R. B. Richardson, D. C. Clay and S. Snapp. 2016. Sustainable Intensification and Farmer Preferences for Crop System Attributes: Evidence from Malawi's Southern Regions. World Development. 87: 139-151.

Palm, C. A., R.J.K. Myers, and S.M. Nandwa. 1997. "Combined Use of Organic and Inorganic Nutrient Sources for Soil Fertility Maintenance and Replenishment" in Replenishing Soil Fertility in Africa. SSSA Special Publication no. 51.

Phiri, A. D. K., G.Y. Kanyama-Phiri and S. Snapp. 1999. Maize and sesbania production in relay cropping at three landscape positions in Malawi. Agroforestry Systems. 47: 153-162.

Rao, S. 2011. Work and Empowerment: Women and Agriculture in South India, The Journal of Development Studies, 47:2, 294-315.

Roxburgh, C. W. and D. Rodriguez. 2016. Ex-ante analysis of opportunities for the sustainable intensification of maize production in Mozambique. Agricultural Systems. 142:9-22.

Rayment, G. E. and F. R. Higginson. 1992. Australian Laboratory Handbook of Soil and Water Chemical Methods. Australian Soil and Land Survey Handbook Vol 3. Pgs. 1-3. Inkata Press, Melborne, Australian.

Roling, N. 2009. Pathways for impact: scientists' different perspectives on agricultural innovation. International Journal of Agricultural Sustainability. 7:83-94.

Rust-Smith, J. 2015. Risk Determinant of Adoption of Conservation Agriculture by Smallholder Farmers in Malawi, In C. Chan, and J. Fantle-Lepczyk (eds.) Conservation Agriculture in Subsistence Farming: Case Studies from South Asia and Beyond. CABI Publishing, Oxfordshire, UK.

Sakala, W.D., G. Cadisch, and K. Giller. 2000. Interactions between residues of maize and pigeon pea and N fertilizers during decomposition and N mineralization. Soil Biology & Biochemistry. 32:679-688.

Sanga, F. and V. H. Kabambe. 2014. Evaluation of agronomic management of leaf litter and inorganic fertilizer on maize (Zea mays L.) grown after a two-year pigeonpea (Canjanus canjanus) fallow in Malawi. International Journal of AgriScience. 4:307-312.

Shepard, K. D., B. Vanlauwe, C. N. Gachengo and C. A. Palm. 2005. Decomposition and mineralization of organic residues predicted using near infrared spectroscopy. Plant and Science. 277:315-333.

Siddique, K. H. M., C. Johansen, N. C. Turner, M. Jeuffroy, A. Hashem, D. Sakar, Y. Gann ad S. S. Alghamdi. 2012. Innovations in agronomy for food legumes. A Review. Agronomy for Sustainable Development. 32:45-64.

Sirrine, D., C. Shennan and J. R. Sirrine. 2010a. Comparing agroforestry systems' ex ante adoption potential and ex post adoption: on-farm participatory research from southern Malawi. Agroforestry Systems. 79:253-266.

Sirrine, D., C. Shennan, S. Snapp, G. Kanyama-Phiri, B. Kamanga and J. R. Sirrine. 2010b. Improving recommendations resulting from on-farm research: agroforestry, risk, profitability and vulnerability in southern Malawi. International Journal of agricultural Sustainability. 8: 290-304.

Smith, A., S. Snapp, J. Dimes, C. Gwenambira and R. Chikowo. 2016. Doubled-up legume rotations improve soil fertility and maintain productivity under variable conditions in maize-based cropping-systems in Malawi. Agricultural Systems. 145: 139-149.

Smith, R. G., Gross, K. L. and G. P. Robertson. 2006. Effects of Crop Diversity on Agroecosystem Function: Crop Yield Response. Ecosystems. 11:355-366.

Snapp, S., P Garbowski, R. Chikowo, A. Smith, E. Anders, D. Sirrine and M. Bekunda. 2017. Maize yield and profitability tradeoffs with social, human and environmental performance: Is sustainable intensification feasible?. Agricultural Systems. 162: 77-88.

Snapp, S.S., Blackie, M. J., Gilber, R. A., Bezner-Kerr, R. and G.Y. Kanyama-phiri. 2010. Biodiversity can support a greener revolution in Africa. PNAS. 107:20840-20845.

Snapp, S. S., M. J. Blackie and C. Donovan. 2003. Realigning research and extension to focus on farmers' constraints and opportunities. Food Policy. 28:349-363.

Snapp, S., 2002. Quantifying farmer evaluation of technologies: The mother and baby trial design. Quantitative Analysis of Data from Participatory Methods in Plant Breeding 9.

Snapp, S.S., G. Kanyama-Phiri, B. Kamanga, R. Gilbert and K. Wellard. 2002a. Farmer and researcher partnerships in Malawi: developing soil fertility technologies for the near-term and far-term. Experimental Agriculture. 38:411-431.

Snapp, S. S., D. D. Rohrbach, F. Simtowe and H. A. Freeman. 2002b. Sustainable soil management options for Malawi: Can smallholder farmers grow more legumes?. Agriculture, Ecosystems and Environment. 91:159-174.

Snapp, S. S. and S. N. Silim. 2002. Farmer preferences and legume intensification for low nutrient environments. Plant and Soil. 248:181-192.

Snapp, S. S. 1998. Soil nutrient status of smallholder farms in Malawi. Communications in Soil Science and Plant Analysis. 29:2571-2588.

Snapp, S. S., P. L. Mafongoya and S. Waddington. 1998. Organic matter technologies for integrated nutrient management in smallholder cropping-systems of southern Africa. Agriculture, Ecosystems and Environment. 71:185-200.

Stephens, E. C., C. F. Nicholson, D. R. Brown, D. Parsons, C. B. Barrett, J. Lehmann, D. Mbugua, S. Ngoze, A. N. Pell, and S. J. Riha. 2012. Modeling the impact of natural resource-based poverty traps on food security in Kenya: The Crops, Livestock and Soils in Smallholder Economic Systems (CLASSES) model. Food Security 4:423-439.

Tiemann, L. K., A. S. Grandy, E. E. Atkinson, E. Maria-Spiotta and M. D. McDaniel. 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecology Letters. 18:761-771.

Tiemann, L. K., S. A. Billings. 2012. Tracking C and N flows through microbial biomass increased moisture variability. Soil Biology &Biochemistry. 49:11-22.

Tiemann, L. K. and S. A. Billings. 2011. Changes in variability of soil moisture alter microbial community C and N resource use. Soil Biology & Biochemistry. 43:1837-1847.

Tittonell, P., A. Mukiuki, C. J. Klapwijik, K. D. Shepard, R. Coe and V. Vanlauwe. 2013. Soil heterogeneity and soil fertility gradients in smallholder farms of the East African highlands. Soil Science Society of America Journal. 77:525-538.

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

Tittonell, P., A. Muriuki, K. D. Shepard, D. Mugendi, K. C. Kaizzi, J. Okeyo, L. Verchot, R. Coe, and B. Vanlauwe. 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. Agricultural Systems 103:83-97.

Tittonell, P. K. D. Shepherd, B. Vamlauwe and K. E. Giller. 2008. 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 & Environment. 123: 137-150.

Tittonell, P., B. Vanlauwe, n. de Ridder and K. E. Giller. 2007. Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: Soil fertility gradients or management intensity gradients?. Agricultural Systems. 94:376-390.

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

Turmel, M., A. Speratti, F. Baudron, N. Verhulst and B. Govaerts. 2015. Crop residue management and soil health: A systems analysis. Agricultural Systems. 134:6-16.

Vagen, T.G., R. Lal and B. R. Singh. 2005. Carbon sequestration in sub-Saharan Africa: A Review. Land Degradation and Development. 16:53-71.

Vanek, S. J. and L. E. Drinkwater. 2016. Integrating scientific and local soils knowledge to examine options by context interactions for phosphorous addition to legumes in an Adean agroecosystem. Experimental Agriculture. 1-24.

Vanlauwe, B. and K. E. Giller. 2006. Popular myths around soil fertility management in sub-Saharan Africa. Agriculture, Ecosystems and Environment. 116: 34-46.

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

Vanlauwe, B., A. H . AbdelGadir, J. Adewopo, S. Adjei-Nsiah, T. Ampadu-Boakye, R. Asare, F. Baijukya, E. Baars, M. Bekunda, D. Coyne, M. Dianda, P. M. Dontsop-Nguezet, P. Edanyat, S. Hauser, J. Huising, A. Jalloh, L. Jassogne, N. Kamai, A. Kamara, F. Kanampiu, I. Mohammed, L. Nabahungu, F. Nielsen, G. Nziguheba, P. Pypers, D. Roobroeck, M. Schut, G. Taulya, M. Thuita, V. N. E. Uzokwe, P. van Asten, L. Wairegi, M. Yemefack and H. J. W. Mutsaers. 2017. Looking back and moving forward: 50 years of soil and soil fertility management research in sub-Saharan Africa. International Journal of Agricultural Sustainability. DOI: 10.1080/14735903.2017.1393038

Waldman, K. B., D. L. Ortega, R. B. Richardson and S. S. Snapp. 2017. Estimating demand for perennial pigeon pea in Malawi using choice experiments. Ecological Economics. 131:222-230.

Waldman, K. B., D. L. Ortega, R. B. Richardson, D. C. Clay and S. Snapp. Preferences for legume attributes in maize-legume cropping-systems in Malawi. Food Security. 8:1087-1099.

Weke, P. G. O., M. W. Muchiri and R. Coe. 2006. The Bradley-Terry Model for Handling Categorical Response Variables from Farmer Participatory Trials. Far East Journal of Theoretical Statistics. 20: 163-178.

World Bank. 2016. Malawi drought 2015-2016: post-disaster needs assessment (PDNA). Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/640011479881661626/Malawi-drought-2015-2016-post-disaster-needs-assessment-PDNA

World Bank. 2006. Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems. 2006. http://siteresources.worldbank.org/INTARD/Resources/Enhancing_Ag_Innovation.pdf Accessed 12 December 2017.