A catalogue of tested crop, soil, and water management options under varied land degradation conditions and socio-economic environment in the target areas in Tanzania, Malawi, and Zambia

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The Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program comprises three research-for-development projects supported by the United States Agency for International Development as part of the U.S. government's Feed the Future initiative.

Through action research and development partnerships, Africa RISING will create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads an associated project on monitoring, evaluation and impact assessment.

Introduction

This study contributed to the objectives of Africa RISING to identify and promote sustainable intensification (SI) pathways by evaluating tested crop, soil and water management options for their suitability under varied land (soil health) and socio-economic conditions that prevail in the target areas in Tanzania, Malawi, and Zambia. This project (i) took stock of what has been learnt in the target areas and in areas with similar agro-ecological conditions from earlier investments in sustainable intensification of smallholder agriculture, (ii) assessed land degradation and access of smallholder farmers to productive land, (iii) assesse the physical and economic accessibility to the essential production factors for implementing improved options, and (iv) assessed the current conduciveness of the political, extension, and economic environment for their adoption. The project analysed secondary information, discussed with key informants, partners, and policymakers, implemented desktop activities around the specific benefits of best bet options, and evaluated agricultural input market chains and the profitability of the supply of essential agricultural inputs.

Objective 1: To avail to partners a set of previously tested soil, crop, and water management options for maize-based farming systems with potential for sustainably intensifying agricultural production and reducing climate-related risk in the target areas

The dominant smallholder cropping systems of eastern and southern Africa are maize-based, being the staple crop. Unfortunately, the soil resource is being degraded, with consequent reduction in crop yields.

In most regions of Africa, soil fertility degradation is caused by three interlinked factors (Ajayi et al., 2011): (i) the breakdown of the traditional fallow system as a result of an increase in human population and decreasing per-capita land availability; (ii) inadequate adoption of soil management investments such as conservation or crop residue incorporation; and (iii) sub-optimal use of fertilizers by a majority of smallholder farmers due to high cost and constraints to access them.

Despite the notable adoption of high-yielding maize by smallholders in Africa (improved germplasm is grown on 33-50% of Africa's maize area), national per-hectare increases in maize productivity are disappointing (Kumwenda *et al*., 1996). Farmers continue to mine the soil as losses of mineral nutrients from the soil generally exceeds nutrient inputs. Presently the challenge of improving productivity without compromising sustainability is so large that farmers will need to combine gains from improved germplasm with complementary improvements in soil fertility and water management. Improved germplasm alone will not be sufficient to meet the challenge.

In this report best bet options for tested crop, soil and water management are identified, summarized and assessed for potential adoption listed by geographical area.

Methods used

The study relied on review of published and unpublished literature and data generated for specific project sites. Apart from the documents provided by the organisations involved directly in the implementation of the projects, the internet was also a key resource. The findings of this analysis are expected to contribute in guiding the implementation of future long-term AfricaRISING project initiatives.

<table>
<tr><td>Activity</td><td>Results</td></tr>
<tr><td colspan="2">Output 1.1: A comprehensive inventory (including secondary/gray literature) of available best bet options for crop, soil and water management compiled, including an annotated bibliography that expands on earlier published work</td></tr>
<tr><td>Activities 1.1: To make an inventory of tested crop, soil, and water management options and assess their adoption potential for a range of environments and farm household type</td><td>There are a number of best-bet integrated soil fertility management (ISFM) technologies which have been tested, generated and recommended for use by smallholder farmers in southern and eastern Africa:

In Tanzania, a number of options were identified (Appendix 1) including:
✓ Water harvesting structures such as pits and tied ridges
✓ integration of crops with agroforestry tree species for soil conservation and fodder
✓ Integrated soil fertility management involving the use of inorganic fertilisers, conservation agriculture, green manure, composts, cereal legume rotations, and combination of P, N and farm yard manure .
✓ Use of hybrid maize seed (CG4142, CG4141, H632, H614 &H6302) + mineral fertilizers
✓ Use of Improved rice seed varieties (SARO, NERICA)

In Malawi and Zambia similar options have been found and prioritized (Appendix 2) and these include:
✓ Legume rotations and intercropping cereals with legumes, such as Cajanus cajan, soybeans, groundnuts and the common bean
✓ Incorporation of crop residue into the soil, application of compost manure, green manures, and farmyard manure (cattle, sheep, goat and chicken)
✓ Systematic inter-planting of maize with Faiderbia albida
✓ Alley cropping/hedgerow intercropping or alley farming)
✓ Undersowing cereal crops with fast growing, high biomass and high N content (such as Tephrosia vogelii, Sesbania sesban, or Cajanus cajan).
✓ Improved fallows using fast growing N fixing tree species that also produce a lot of biomass (e.g., Tephrosia vogelii, Sesbania sesban, or Cajanus cajan) (Ikerra et al., 2001).
✓ Promotion of conservation agriculture in maize-based systems (manual use of hand-hoe, dibble stick or jab planter; mechanised systems involving use of animal traction of a ripper or direct) all with inorganic or organic fertiliser; Rotations with crop legumes; Weed control.
Despite that most of these options are attractive in increasing productivity, the technologies are not well adopted due to unavailability/affordability of required inputs such as seeds, manures and fertilizers; their benefits were not so obvious to farmers such as non-food/cash grain legumes; high labour demands as in the case of construction of physical structures; and some of the technologies having delayed benefits.</td></tr>
<tr><td colspan="2">Output 1.2: Detailed descriptions of the best bet technologies and performance in terms of yield, yield per rain and fertilizer input, stability of yield, profitability of the technologies, and other services of the technologies including fuel wood, forage, soil fertility and soil organic matter provision</td></tr>
<tr><td>Activities 1.2:</td><td>Evidence of Impact of best-bet technologies</td></tr>
</table>

To summarize the observed increases in crop productivity, stability of crop response across variable climatic conditions, and water and nutrient use efficiency of above options for the target agro-ecological conditions

Preliminary synthesis from the set of database created for the options shows that recommended fertilizer rates increase crop productivity variously from site to site. Optimum yields (4 t ha^{-1} and above) may be obtained with N application between 46 to 107 kg N ha^{-1} (Figure 1), though the Tanzania sites yielded ≤3 t ha^{-1} even with application of 120 kg N ha^{-1}. Fertilization with N and P may be economical at applications of 30-120 kg N ha-1 and 0-40 kg P ha-1 as shown by some data from Tanzania (Table 1). However, it is notable that the variation between the sites is very high to enable make blanked recommendation.

Evidence from trial sites in Malawi and Zambia suggest that significant crop yield increases are achieved under conservation agriculture (CA) compared to conventional farmer practice, but after at least 3 consecutive seasons (Figure 2).

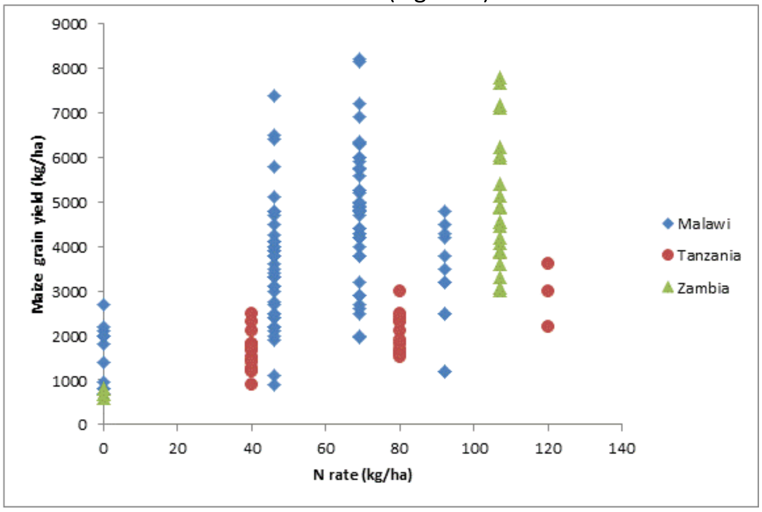

Fig 1: Maize yield response to N application in different sites in Malawi, Tanzania and Zambia

Table 1: Economic analysis of maize and rice fertilization at nine Tanzania sites.

Crop	Nutrient rates		MRR*
	N	P	(%)
	Kg ha^{-1}		
Maize	0	20	156
Maize	0	40	18
Maize	0	0	0
Maize	30	0	206
Maize	80	20	241
Rice	40	0	409
Rice	120	30	296
Rice	120	0	344
Rice	40	20	766

***Favourable MRR (Marginal rate of return) should be ≥ 200%**

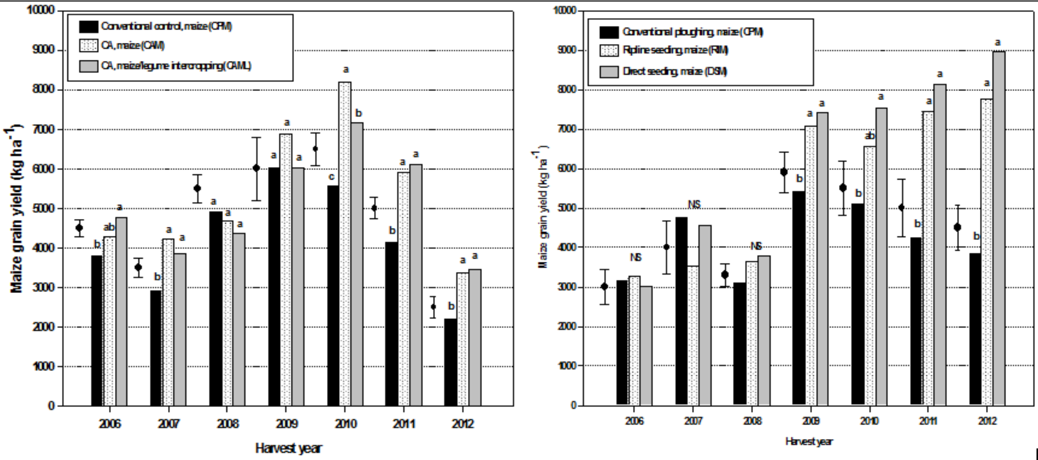

Figure 2: CA and rip-line seeding effect on longer term maize yields on farmers' fields in Malawi (Source: Thiefelder et al., 2012)

Agroforestry has provided farmers with options to improve soil fertility without incurring the often high cost of inorganic fertilisers. The technology uses leguminous trees which fix nitrogen in the soil and generate large quantities of biomass that is used as green manure to improve soil quality. Once established, the leguminous trees can be easy to maintain.

Annual legumes are used as sole crops in rotation with cereals, are intercropped, or are occasionally used as green manures. Perennial legumes are sometimes retained in farmers' fields and are just beginning to be incorporated as hedgerow intercrop or alley crop systems. Giller et al. (1994) conclude that biological N fixation from legumes can sustain tropical agriculture at moderate levels of output, often double those currently achieved. Under favourable conditions, green manure crops generate large amounts of organic matter and can accumulate 100-200 kg N/ha in 100-150 days in the tropics.

The annual yield increase from fertilizer tree fallows ranges between 2 and 4 times the yield from continuous maize production without fertilizer. Fertilizer tree fallows produce between 50 and 100 % more maize over 3 seasons than does continuous maize production without fertilizer over 5 seasons (Table 2) (Ojayi et al. 2009).

Table 2. Maize yields after 2-year *Sesbania sesban* and *Tephrosia vogelii* fallows in farmers' fields: 1998 to 2000 (Source: Ojayi et al. 2005)

Fallow Species	Maize Yields (tones ha $^{-1}$)			
	Land Use System	Year 1	Year 2	Year 3
Sesbania sesban	Sesbania fallow	3.6	2.0	1.6
	Fertilized maize	4.0	4.0	2.2
	Unfertilized maize	0.8	1.2	0.4
	LSD 0.05	0.7	0.6	1.1
Tephrosia vogellia	Tephrosia fallow	3.1	2.4	1.3
	Fertilized maize	4.2	3.0	2.8
	Unfertilized maize	0.8	0.1	0.5
	LSD 0.05	0.5	0.6	0.9

Studies in Malawi showed increased infiltration under four CA technologies compared to conventional ploughing (Figure 3). In the same studies, CA (direct seeding of maize) was observed to keep higher moisture contents (16.5% at 0-10 cm depth and 22.5% at 10-20 cm depth) compared to compared to Conventional tillage (13.5% at 0-10 cm depth and 19.4 % at 10-20 cm depth) (Thierfelder and Wall, 2010).

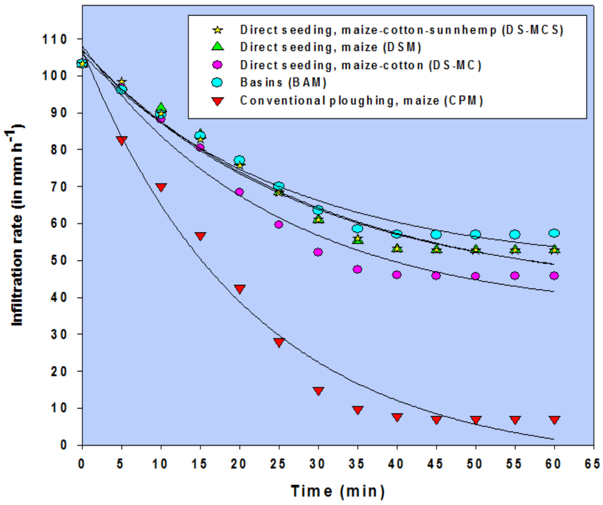

Figure 3: Water infiltration rates under four CA practices and conventional tillage in Malawi.

Output 1.3: A set of existing dissemination and training materials related to best bet technologies and developed for specific stakeholder groups

Activities 1.3: To collate existing dissemination and training materials related to tested best bet crop, soil, and water management options

A wide range of products have been developed mainly by CG Centres to support the tested best bet crop, soil and water management options. A total of A total of 43 materials have been identified so far which can be broken down into broad categories as follows: Agroforestry (5); Conservation Agriculture (CA) (13); CA and Fertiliser management (6); Legumes and Biological Nitrogen Fixation (BNF) (18); and others (1) (Table 3). Although some of the materials are not site specific, there is potential for adapting them to specific settings.

Table 3: Summary of dissemination and training material on the options

Option	No. of dissemination/ training materials	Institution
Agroforestry	5	ICRAF
Conservation Agriculture	11	CIMMYT
	2	ACT Network Southern Africa
Legumes and Biological Nitrogen Fixation	18	TSBF-CIAT/N2Africa
CA and fertilizer management	6	ICRISAT
Fertiliser guidelines	1	Ministry of Agriculture, Malawi

Most of the materials have been targeted at Training of Trainers and Lead Farmers. However, material destined for lead farmers is largely in English and needs to be translated into vernacular for effective use. One clear gap is the lack of a dissemination/training material on Production and Management of Organic Manure especially on livestock manure which should complement other sources of crop nutrients. More details of the materials and sources are described in Appendix 3.

Lessons learned

A number of issues that CG centres are trying to address are closely linked in a way and are complementary when considered together enhancing crop/soil productivity for increased food security. Since the target user of the research and development outputs is the same person – the farmer; collaboration should the natural route to take. Hence there is a lot of scope to develop larger, multi-institutional and multi-year research programmes which address all facets at the same time. Another lesson learned is that research and technology development should target both the ecological conditions and the farmers' socio-economic conditions. Networking among stakeholders is important for successful technology dissemination and service delivery

Objective 2: To identify land degradation hotspots and soil health constraint envelopes and their implications for crop response characteristics to fertilizer application and soil improvement

Land degradation is a serious environmental and socio-economic problem that threatens ecosystem health and food security in sub-Saharan Africa (SSA). It is estimated that soil erosion, one form of land degradation, is responsible for up to 40% yield reduction in SSA (Dregne 1990; Lal, 1995). Since degradation processes do not affect all areas of a region equally, knowledge of hotspot areas that require priority intervention is necessary. Understanding key biophysical and socio-economic attributes of the region is critical for developing site-specific and problem-oriented land management measures.

Until recently, the increase in food production in most countries was achieved by increasing the agricultural land area. However, reserves of potentially arable prime agricultural land are dwindling and the remaining land was retained for numerous purposes, including the provision of essential ecosystem services. There is a need for efficient use of available resources. Effective fertilizer and seed technologies are believed to be one of the effective ways to both improve production while sustaining the environment. It is reported that rainfed cereal yield can be increased with a factor of five in Africa from the current average of 1.5 to 5.8 tonnes dry matter ha^{-1} per crop cycle under rainfed conditions without growth limitations from nutrients, insects and diseases (Conijn et al. 2011). Current average fertilizer rates are well below 10 kg N ha^{-1} across Africa compared to 120 kg N ha^{-1} in Asia. Therefore large amount of nutrients inputs are required to realize increase in crop productivity levels in Africa to two or three times current levels. Knowledge of the spatial distribution of nutrient constraints is necessary to target specific areas with specific recommendations. It is also important to understand the requirements (socio-economic and environmental conditions) of inputs to provide their envisaged objectives.

Objective

The 2nd objective of this Africa RISING initiative was aimed to assess the ecological conditions and idenify ecological constraints to agricultural productivity in the areas of interest in Tanzania, Malawi and Zambia. In addition, we aimed to analyze crop response patterns to fertilizer treatments using existing data.

Methods Used

This objective relied on existing information of soils, climate, land degradation risk and fertilizer recommendations to provide guidance on the applicability of best bet options to improve land productivity and food security. For assessment of prevalence rates of land degradation and soil health constraints in the target areas, the project used biophysical baseline data collected using the Land Degradation Surveillance Framework (LDSF) in the Africa Soil Information Service (AfSIS) project. LDSF sites are 100 sq. km in area. Specifically, three sentinel sites in Tanzania, three in Zambia and two sites in Malawi were included in this study. These sites were sampled in 2010 and 2011 (**Error! Reference source not found.**). Data from diagnostic trials conducted by the AfSIS project in four of these sentinel sites were used to demonstrate crop response characteristics to fertilizer application and soil amendments in relation to soil constraint envelopes. The LDSF ecological data such as land use, dynamic soil properties, terrain characteristics and erosion prevalence were analysed to identify key ecological metrics such as proportion of cultivated areas, tree density, soil depth restriction and carbon concentrations. In addition, predictive models were developed to assess the probability of erosion prevalence across the region.

The results of this report are expected to contribute to the implementation of the long-term Africa Rising project initiatives.

<table>
<tr><td>Activity</td><td>Results</td></tr>
<tr><td colspan="2">Output 2.1:
Organize available data sets and assess their suitability. Develop prediction models for land degradation and soil health.</td></tr>
<tr><td>Activities 2.1: Collate survey data from the LDSF conducted in the region (incl. spectral data, soil sample data, etc.) and analyze ecological metrics (LDSF data), to determine land degradation and soil functional properties of the sentinel landscape</td><td><u>Study Sites</u>: Since the ‘jump-start’ projectes were for 6-months, we organized available data from the AfSIS project, National Agricultural Research Insitutes and other sources in order to create a comprehensive assessment of biophysical contraints to agricultural production. We selected data for the Africa Rising mandate area in southern and East Africa from the following countries: Tanzania, Malawi and Zambia (Figure 4).

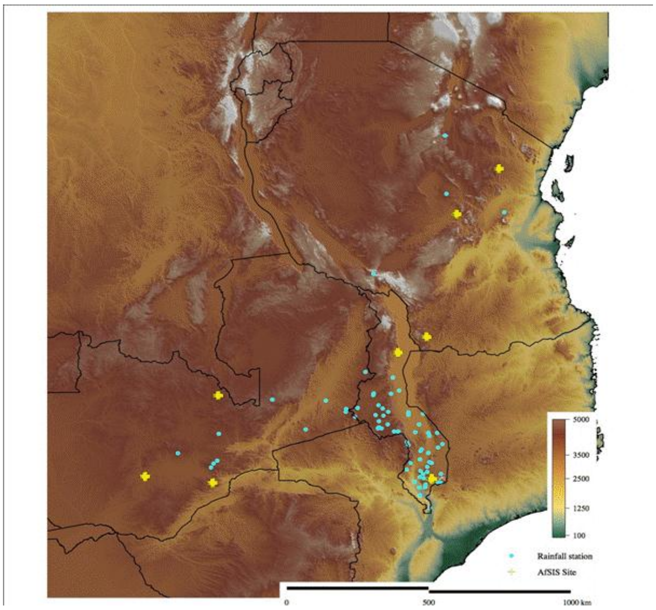
Figure 4: Location of the eight AfSIS sentinel sites in Tanzania, Malawi, and Zambia and location of rainfall stations, from which long-term rainfall data was shared for this project.

<u>Land Degradation Surveillance Framework (LDSF) data and analysis</u>
LDSF data were organized for eight sites in the three countries mentioned above. These data were analyzed to derive a suit of ecological mertices such as land use, tree density, root depth restrictions and soil erosion prevalence for sites within the AfricaRising regions in three countries of interest. These data are used to assess the soil health and land degradation status of the regions, and identify major biophysical constraints to production.

<u>Soil sample analysis</u>
Over 2000 soil samples collected from the eight sentinel sites by the AfSIS project (**Error! Reference source not found.**). These samples were analyzed using near-infrared spectroscopy at the two CIAT regional laboratories (Lilongwe, Malawi and Arusha Tanzania). Reference samples were analyzed for carbon and nitrogen at the ICRAF soil and plant spectroscopy laboratory in Nairobi, Kenya. We present soil organic carbon and total nitrogen data for the sites in Tanzania and Malawi only, as Zambia sites were not analyzed in time.

<u>Rainfall Variability</u>: Long-term rainfall data was shared by the NARS partners in Zambia, Malawi, and Tanzania for all stations marked in Figure 5. Analysis of seasonal rainfall data</td></tr>
</table>

reveals that rainfall variability varies across regions. For example, Figures 5 illustrates the variation in long-term monthly rainfall data for Morogoro and Lusaka stations in Tanzania and Zambia, respectively. Both sites have high rainfall variation throughout the year (Figure 5). These data are important in order to assess the climate risk for farmers in terms of rainfall amounts during the growing season. Strong variability of rainfall (mainly at the onset of the rainy season) could have serious implication on both farmers' planning and the actual crop yield.

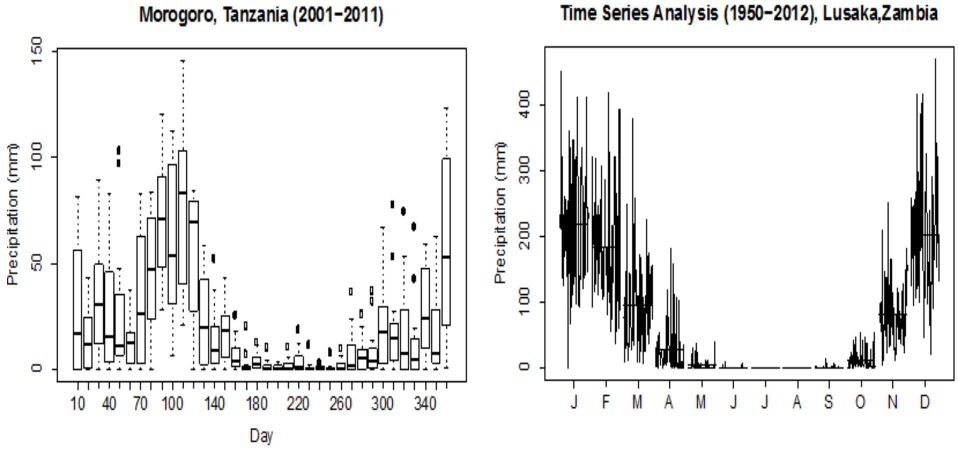

Figure 5: Rainfall data from Morogoro, Tanzania (10-yr data) and Lusaka, Zambia (60-yr data). These data illustrate high variation in monthly rainfall.

Extent of cultivated area: Results indicate that most sites have a mix of cultivated and non-cultivated areas, indicating the need for tools which sample and address complex landscapes encompassing multiple land uses (Figure 6). In contrast, almost 100 % of the Thuchila, Malawi is cultivated.

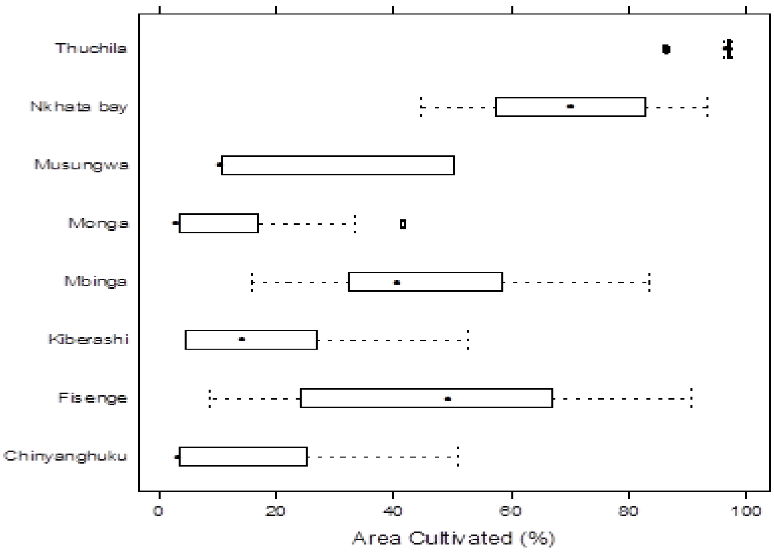

Figure 6: Percent of area cultivated in each site.

Tree Densities in Cultivated Areas

All sites had higher tree densities in non-cultivated areas compared to cultivated areas, as expected (Figure 7). The relatively high tree densities in cultivated areas indicates the potential of agroforestry measures to be adopted and ultized on the farm.

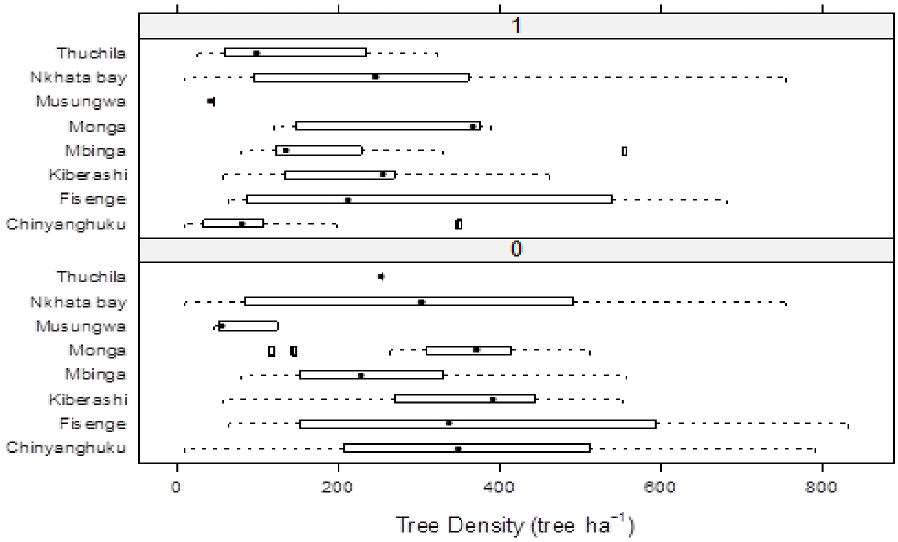

Figure 7: Tree densities in cultivated (1) and non-cultivated (0) plots within the eight sites.

Soil Depth Restriction: The soil depth as measured by an auger restriction at 20 cm depths indicates the land suitability for crop cultivation. Generally, shallow soils (soils which have severe depth restrictions within 20 cm) are less suitable for crop cultivation. Data analysed (not shown) illustrated that most sites did not have severe depth restrictions within 20 cm, indicating that farmers choose lands more suitable for cropping.

Soil organic carbon (SOC): SOC is one of the key factors that affect soil condition and crop yield. Information on the spatial variability of SOC is useful to assess soil nutrient constraint and plan management intervention. SOC values were highly variable within all sites. In general topsoil organic carbon concentrations were higher than subsoil, as expected (Figure 8). Nkhata Bay in Malawi has diversified land use/cover types and this may be the reason for the high SOC variability within the site. These data are important for relating crop yield and SOC content.

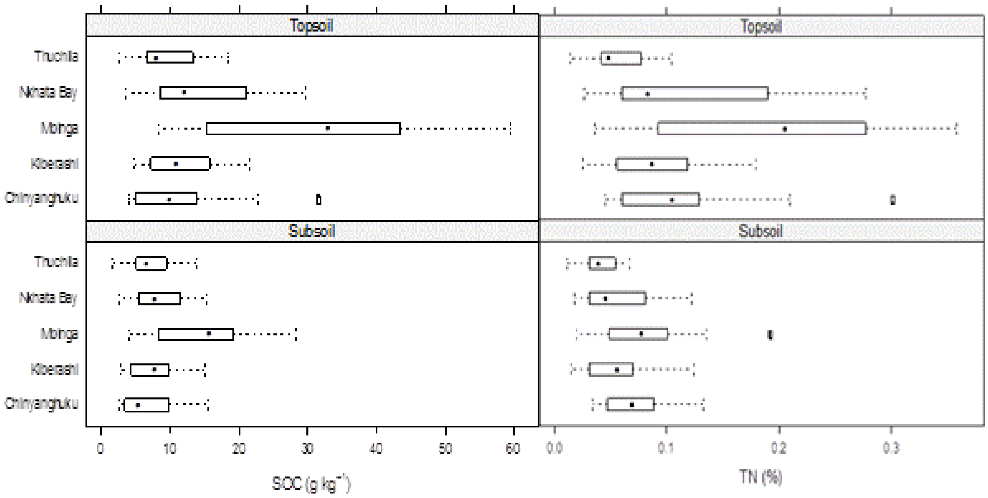

Figure 8: Organic carbon and total N concentrations in topsoil and subsoil for three sites in Tanzania and two sites in Malawi.

Soil total nitrogen (TN): Total nitrogen is also an important variable for assessing soil health. Topsoil nitrogen conentrations were much higher than subsoil concentrations (**Error! Reference source not found.**).

<table>
<tr><td></td><td><u>Erosion prevalence</u>: Erosion prevalence is an important indicator of land degradation. The prevalence of soil erosion at the eight sentinel sites is shown in Figure 9. Chinyanghuku (Tanzania) and Monga (Zambia), have the highest erosion prevalence of over 90% while Mbinga, Kiberashi (Tanzania) have about 50% erosion prevalence. This vital information can be used to plan suitable management measures to reduce erosion. Cultivated areas in Thuchila and Mbinga had higher erosion prevalence compared to non-cultivated areas. Future analysis will focus on the key drivers and factors that determine the spatial variability of erosion risk.


Figure 9: Average erosion prevalence for each of the eight sentinel sites.</td></tr>
<tr><td colspan="2">Output 2.2: Constraint envelopes for selected landscapes using soil carbon as a soil health indicator</td></tr>
<tr><td>Activities 2.2: Collate and analyze data from diagnostic trials to diagnose soil health constraints using carbon as an indicator and determine response crop patterns in relation to</td><td><u>Crop Yield Data</u>
In much of SSA, land productivity is generally low (mostly less than 1 t ha^{-1}) on unfertilised rain-fed croplands because of low inherent soil fertility and inappropriate soil management practices. Sustainable land and water management techniques can increase productivity through integrated soil fertility management where rainfall is reliable. Crop yield data from diagnostic trials on 150 different farmers' fields on five sentinel field trials (Kiberashi and Mbinga in Tanzania and Nkhata Bay, Kasungu and Thuchila in Malawi) was analysed.

<u>Crop Response pattern</u>: In most cases, Nitrogen (N) and Phosphorus (P) were the most limiting nutrients, except on non-degraded sites like Kiberashi (recently converted from natural vegetation/forest) where only N seemed to be the limiting factor (Figure 10). Potassium (K) was only a constraint at one site, Mbinga. Amendment with manure resulted in increased yield relative to NPK treatments, which was used as a reference at all the sites. Overall, liming did not show a strong effect, although several fields in Nkhata bay showed that liming was required.</td></tr>
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soil carbon.

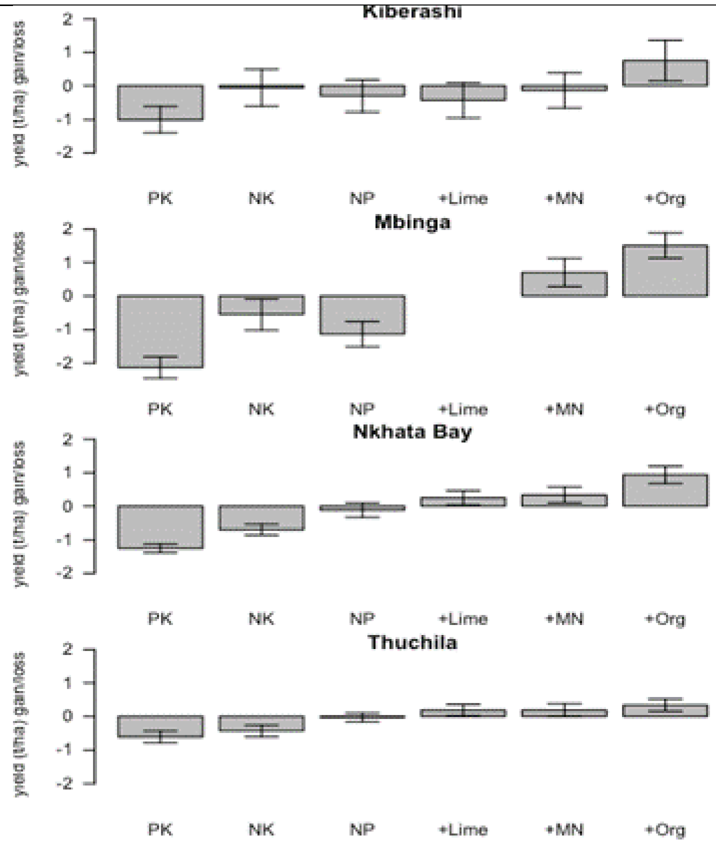

Figure 10: Crop responses (using NPK as reference) observed in tested sites. +lime =NPK+Lime, +MN=NPK+Multinutrients, +Org=NPK+Manure. Error bars are confidence limits.

Crop Response pattern in relation to carbon: Mixed effects models were used to predict expected crop yields given different levels of control yields (Figure 11). In all cases, and consistent with expectations, the response to different treatments decreased with increasing level of control yields which is used as an indicator of soil fertility (proxy for soil carbon). With further refinement, including addition of more covariates in the prediction models, one can get a general indication of expected response given control yields. This work will continue, including the five sentinel sites.

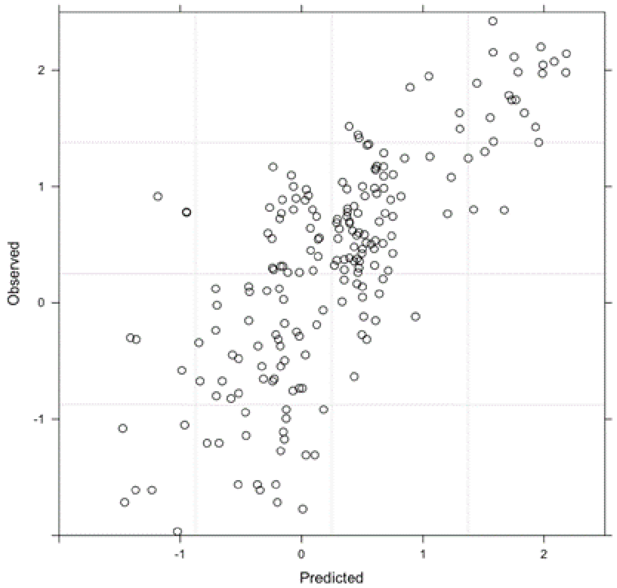

Figure 11: Maize response to different treatments with relation to control (unfertilized) yields. Data used is for four sentinel sites in Tanzania and Malawi.

<table>
<tr><td colspan="2">Output 2.3: Soil carbon deficiency prevalence data, and associated crop response characteristics</td></tr>
<tr><td>Activities 2.3: Predict land degradation (carbon deficiency prevalence), soil health constraints and attainable yield levels (maize) for the target areas.</td><td>Relationship between land degradation and attainable yield levels:
Figure 12 demonstrates the relationship between crop response and soil near-infrared spectra, though based on a limited number of sentinel sites where diagnostic trials were conducted. Although this methodology and prediction models are applicable within the sampled sites, there is scope to extend beyond these sites and develop a general prediction model for wider application. The models provide an opportunity to inform farmers in the region what is the expected yield and yield increments following application of various nutrients and amendments. The use of crop spectra maybe better than relating crop growth with individual/selected soil parameters since the spectra contains integrated information. We propose further work in the proposed full scale AfricaRising project to refine and widen the applicability of the model.
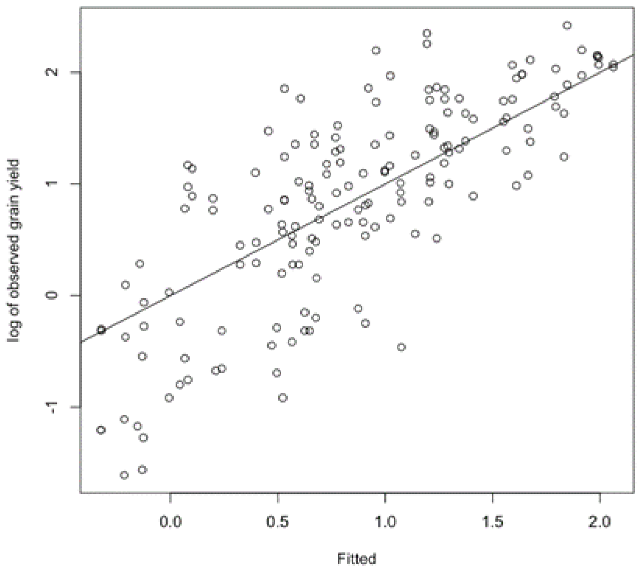
Figure 12: Relationship between observed and fitted maize grain yield of the control (unfertilized) treatments based on soil MIR spectra ranges. r=0.78</td></tr>
</table>

Technologies introduced /evaluated

1. Rapid soil analysis methodologies: near-infrared spectroscopy (NIRS) was used.
2. The relationship between soil spectra and crop response was evaluated.
3. Application of co-located LDSF sites with agronomic trials in order to assess ecological constraints to agricultural productivity can be used as a framework for future monitoring.
4. Data analysis workflows and predictive models developed that can easily be adapted in future analysis

Lessons Learned

This objective relied on existing data within the project area. The collaboration with the NARS in order to gain access to long-term rainfall data was particularly fruitful. This collaborative effort offered opportunities for the different scientists who would ordinarily be working independently to work together on common issues like soil fertility management, rainfall variability and land degradation, which affect agricultural development. The project also offered opportunities to bring together data and information from the different countries for more robust analysis that were not possible initially without this cross-country project. There is need to continue to cultivate and nurture the culture of collaboration across CGIAR centers.

Links with other research and development projects

Objective Two of the Africa Rising project relied heavily on the data collected within the Africa Soil Information Service (AfSIS). The project also collaborated with "Total Land Care" in Malawi, mainly to share data and experiences in land management practices.

Concluding remarks

A key contribution of this early-win exercise was collecting and organizing existing ecological, climate and agronomic data from the three countries. Results are presented for key issues involving land degradation and crop management options. In a long-term project we anticipate to undertake more detailed modelling including identification of land degradation hotspots, identifying and mapping land management options, assessing the probability of drought, modelling soil moisture conditions and crop yield, and extending fertilizer trails to develop fertilizer recommendation decision support tool. We would like to conduct further analysis on time series rainfall data and its effects on yield potential. It will also be vital to design detail impact assessment including cost-benefit and trade-offs of management options. This project identified gaps in existing information, specifically, the need for more data within the Africa Rising project area, including co-located ecological and agronomic monitoring networks. Detailed maps on the spatial variability of landscape and soil properties can also be produced with additional site surveys in the three countries, mainly Malawi and Zambia as there severe data gaps, in terms of LDSF sites.

We identified erosion prevalence (and its high variability), low total soil nitrogen and low soil organic carbon as important barriers to agricultural productivity. These data also highlighted the complexity within landscapes. For example, each 100 sq. km site often contained a mixture of land uses including cultivated and non-cultivated areas. This illustrates the importance of multi-scale sampling designs and robust predictive models in order to address the landscape variability in soil health and ecological indicators. Nitrogen and phosphorus were identified as limiting nutrients in the four trial sites in Malawi and Zambia.

Objective 3: To evaluate the availability to smallholder farmers of inputs required to implement above options in the target areas

Methods used

The study relied on review of published and unpublished literature and data generated for specific project sites. Apart from the documents provided by the organisations involved directly in the implementation of the projects, the internet was also a key resource. The findings of this analysis are expected to contribute in guiding the implementation of future long-term AfricaRISING project initiatives.

Activity	**Results**
Output 3.1: A set of inputs and the specific composition of these inputs (e.g., fertilizer composition; specific varietal needs)	
Activities 3.1: To take stock of the required agricultural inputs needed to implement tested best bet crop, soil, and water managemen t options	There was inadequate data to complete the 'input requirements for the different options analysis' in the time-frame available. This activity can still be carried out during the second phase of the Africa RISING project. However, it was observed that CA requires herbicides applied using knapsack sprayers, a technology available in most areas where cotton is also produced. CA only works well where there is strong extension support and where the required inputs are available.
Output 3.2: An analysis of the physical availability and accessibility of the various agricultural inputs needed to implement and disseminate best-bet options	
Activities 3.2: To assess the availability of above inputs in the various target areas	Inputs have largely been availed through donor-funded programmes where inputs are subsidized and accessed either through paper-based or electronic vouchers. Limited agrodealer network limits availability of inputs in most remote areas. There is potential to run mobile depots or using farmer associations as distribution channels. Most agro-dealers do not have enough stock to supply farmers at the beginning of the cropping season when there is peak demand. It is therefore mechanisms be put in place to facilitate access to credit for purchasing the required inputs at the right time. The crude calculation of access to agro-dealers by farmers in the target areas suggest that the best agro-dealer service is in Malawi and the worst in Zambia (Table 4). Thus Zambian farmers may find it more difficult to access inputs compared to other countries. More effort is required by all players to facilitate wider distribution of agrodealers. In Zambia, the limited supply of no-till planters, jab planters, chaka hoes and rippers, has resulted in a reduced number of potential CA adopters as some of this equipment has to be imported from Zimbabwe (Mazvimavi, 2011).

Table 4: Potential access to inputs in the 3 target countries

Country	No. of agro-dealers	% Rural Population	Estimated No. of HHs/agrodealer	Source
Malawi*	1200	80	1,556	Chinsinga, 2011
Tanzania*	2700	80	2,222	IFDC annual report, 2011
Zambia**	50	60	3,081	District data, 2012

- *Numbers estimated from national figures
- **District data from DACO Chipata, for the two target districts.

Some agroforestry species require the establishment of nurseries whereas others like Tephrosia can be obtained by direct seeding. Gliricidia seedlings take time to establish and are not easily available should farmers need them at a wide scale.

Output 3.3: Cost limitations for accessing and acquiring inputs needed to achieve net returns on investment for the various management options

Activities 3.3: Sensitivity analysis of effects of varying prices of inputs and outputs on the profitability of technologies derived from objective 1 and 2.

The two options where comprehensive sensitivity analyses have been conducted are CA and Agroforestry

Conservation Agriculture:

Literature shows that CA reduces production costs, increase rainfall water use efficiency and improve production (Ernstein et al. 2008). However, in most cases CA results in higher total variable costs resulting from purchase of herbicides and hiring of knapsack sprayers, or hiring draft animals or purchase of rippers (Mazvimavi, 2011; Ngwira et al., 2012). This is offset by higher gross margins realized under CA systems.

A profitability analysis of ripping in maize compared to conventional ploughing found that ripped fields had higher net profit per hectare than ploughed fields (Kabwe et al. (2007) (Table 5). This was attributed to the higher mean yield obtained from ripped fields than ploughed fields as a result of:

- Ripper use which resulted in efficient use of fertilizer;
- Plot size where smaller plots mean more intensive management under ripping and thus higher yield; and
- Higher fertilizer application under ripping.

Of the total cost under ripping, 48% associated with labour cost while 37% attributed to the cost of inputs. Total cost under ploughing showed that about 45% came from labour cost and 35% came from cost of the inputs. Even though total maize production cost per hectare was higher in Eastern Province, maize was more profitable there compared to Southern Province. Both labour and fertilizer costs were higher in ripped maize fields than in ploughed fields.

Table 5: Profitability analysis of the Magoye Ripper on Maize production for 2004/05 (Kabwe et al., 2007)

	Eastern Province		Southern Province	
	Maize ripped field	Maize ploughed field	Maize ripped field	Maize ploughed field
Output (kg/ha)[a]	2,350	1,479	1,224	1122
Output price (ZMK/kg)[b]	788	788	782	782
Gross Income per ha	1,851,800	1,165,452	957,168	877,404
Cost of labour (ZMK/ha)				
Land preparation	85,655	96,525	59,932	61,400
Planting	39,807	35,861	32,000	26,900
Fertilizer application	56,818	32,506	25,852	18,725
All weeding	108,594	108,003	90,000	86,139
All harvesting activities	126,538	63,776	56,675	50,252
Cost of Inputs(ZMK/ha)[a]				
Cost of fertilizer per ha	251,350	205,656	200,000	198,700
Cost of seed per hectare	66,545	56,250	93,714	103,920
Cost of the implement (ZMK/ha)				
Magoye ripper*	12,500		12,500	
Mouldboard plough*		43,700		43,700
Beam	12,500	12,500	12,500	12,500
Other Costs (ZMK/ha)				
Cost of sharpening the tine*	5,000	0	5,000	0
Cost of hiring animal to pull the plough or ripper	100,000	100,000	100,000	100,000
Total cost per ha	**865,307**	**754,777**	**688,173**	**702,236**
Net Income	**986,500**	**410,700**	**269,000**	**175,200**
Provincial difference (EP-SP)	**717,500**	**235,500**		

Source: FSRP/GART Ripper Study 2005, * The values of the Magoye ripper and mouldboard plough have been calculated considering the depreciation. The cost of the mouldboard plough is apportioned to the total area under maize, cotton and other crops grown by the farmers. The cost of the Magoye ripper is apportioned to the total the ripped fields of maize and cotton in equal amount since it is assumed the farmers only used the ripper in these crops. The cost of the beam is calculated considering the life span of about 15 years.
(a) and (b) asterisks show where the median and the mean have been used.

1USD = ZK4,500

In a long-term study (6 seasons) at 2 sites (Lemu and Zidyana) in Malawi, Ngwira et al. 2012) provided strong evidence of the consistent economic benefits of CA only and CA plus a legume intercrop which became significant after at least 4 seasons (Table 6). This is aside the biophysical benefits to the soil and the reduced erosion that comes with the CA. In Lemu, both CA systems resulted in more than three times higher net returns compared with conventional tillage systems. In Zidyana, CA systems resulted in 32 and 23% higher gross margins with CA monocrop maize and CA maize–legume intercrop, respectively, than conventionally tilled maize.

Table 6: Farm Enterprise Budget Analysis for CA and Conventional Practices in Malawi (2005-2011) (Source: Ngwira et al. 2012).

	Lemu			Zidyana		
	CP	CA	CAL	CP	CA	CAL
Gross receipts	528.6	881.5	979.7	1047.2	1309.5	1293.7
Variable costs						
Inputs	238.5	341.0	353.6	221.7	323.7	346.1
Labor days (6h days)	61.7	39.9	49.4	61.7	39.9	49.4
Labor costs	159.5	103.2	127.9	155.6	100.7	124.7
Sprayer costs		1.7	1.2		1.7	1.2
Total variable costs	398.1	445.9	482.8	377.3	426.1	472.1
Net returns (US$ ha^{-1})	**130.5**	**435.5**	**497.1**	**669.9**	**883.3**	**821.9**
Returns to labor (US$ per day)	1.8	5.2	4.9	5.4	9.8	7.6

Note: CP, conventional practice; CA, conservation agriculture sole maize; CAL, conservation agriculture maize–legume intercrop.
Labor data (in person hours and minutes) was obtained from one on-farm trial per site for each operation (laying crop residues, tillage, herbicide application, planting, fertilizer application, weeding, harvesting, etc.).
Price data were based on all applied inputs (seed, herbicides, fertilizers, etc.) from each of the plots during the entire period of the study.

In Mbeya district of Tanzania, Shetto and Owenya (2007) reported that conservation agriculture research farmers reduced fertilizer application by half, from 125 kg/ha to 62.5 kg/ha, saving US$58.75, while increasing maize yield from 1125 kg/ha to 2250 kg/ha and sunflower from 750 kg/ha to 2700 kg/ha. Net benefits increased by more than threefold for sunflower and fivefold for maize, mainly by selling surplus maize, increasing sunflower production and reducing cash outlays because farmers did not have to hire labour for weeding.

Agroforestry:

A financial profitability analysis of the different farming practices in Zambia done by Ajayi et al. (2009) showed that agroforestry practices produced a discounted net benefit ranging between US$233 and US$309 ha^{-1} compared to net a benefit of US$ 130 obtained with unfertilised maize, the commonest practice used by an average smallholder farmer in Zambia (Table 7). The net benefit of agroforestry practices was 44 to 58% superior to non fertilised continuous maize production practice. With a net profit of US$ 499 ha^{-1}, subsidised fertilised maize was the most financially profitable of all the soil fertility management practices, given Government of Zambia's 50% subsidy on fertiliser at that time. However, after accounting for the subsidy in the computation, the net benefit of fertilised maize fell to US$ 349 ha^{-1}, and the difference between fertilised maize and agroforestry practices reduced sharply from 61% to 13% (Ajayi et al. 2009).

In terms of returns per unit of investment cost, Ajayi et al. (2009) found that all the three agroforestry practices performed better than conventional practices as they yielded higher returns per unit investment cost than continuous maize fields with or without fertiliser. Each unit of money invested in agroforestry practices gave returns ranging between 2.77 and 3.13 in contrast with 2.65 obtained in fertilised maize practice (subsidised), and 1.77 units in fertilised maize (non-subsidised). The return to labour per person day was $3.16 in fertilised fields (subsidised), $2.56 in fertilised maize (open market price) and $1.10 in unfertilised maize fields. For the three agroforestry practices, the return to labour per person day was $2.63 for Gliricidia, $2.41 for Sesbania and $1.90 for Tephrosia fallow.

Table 7:Profitability of the different maize production systems over a five-year cycle in eastern Zambia (Ajayi et al. 2009)

Soil fertility management practice	Fallow period (no. of years)	Maize cropping (number of years)	NPV (US$ ha^{-1})[a]	BCR
Continuous maize without fertiliser	0	5	130	2.01
Continuous maize with fertiliser (fertiliser subsidised at 50%)	0	5	499	2.65
Continuous maize with fertiliser (open market priced fertiliser)	0	5	349	1.77
Gliricidia-maize intercrop	2	3	327	3.11
Sesbania-maize rotation	2	3	309	3.13
Tephrosia-maize rotation	2	3	233	2.77

[a] US$ 1=4,500 Zambia Kwacha

NPV = Net present value; BCR = benefit cost ratio

Measurable outputs/deliverables

(a) Technologies evaluated – directly or indirectly:

- Conservation Agriculture
- Agroforestry
- Recommended fertilizer application

(b) Lessons learned

There is insufficiency of agro-input dealers especially in Zambia and Tanzania, an issue needing to be addressed. The CG centres can collaborate with relevant government departments, other supporting organizations and donor agencies to ensure increased supply of agricultural inputs close to the farmers. Studied technologies such as CA and agroforestry are profitable to the farmers and have positive environmental effects at the farm and landscape levels. Hence there is a lot of scope to develop larger, multi-institutional and multi-year research programmes which address all facets at the same time.

Objective 4: Assessment of the Political and Extension environment for dissemination of tested soil, crop and water management options

This report highlights the agricultural policies that relate to the dissemination of best crop, soil and water management options. It also documents some of the initiatives that have been implemented with the intention of intensifying agriculture and sustainable land management and further highlights the various dissemination approaches used in extension towards the target communities.

Implementation Strategy

The study used a combination of primary and secondary sources of information to address the objectives. The tools used to collect data included desk research and literature review and key informant interviews.

a) Desk research and literature Review

Various literature and documentation relevant to the study were collected, reviewed and analyzed. The reviewed literature will provided background information and data that already exists. The key documents reviewed included:

- Government sector and sub-sector policy documents
- Government strategy documents
- Project reports
- Publications

b) Stakeholder consultations and key informant interviews

The study also involved holding meetings with relevant people in relevant government ministries, non-governmental organizations, and donor agencies. The aim of the meetings was to collect primary information regarding crop, soil and water management options. Discussions were be guided by a checklist of issues relevant to objective four of the Logical Framework. The consultation meetings were also used to collect documentation relevant to the study that the stakeholders had in possession.

Objective 4: Assessment Of The Conduciveness Of The Political And Extension Environment For The Dissemination Of Tested Soil, Crop, And Water Management Options In Tanzania, Malawi And Zambia	
Activity 4.1: To document various initiatives that have been implemented in the target areas aimed at agricultural intensification and sustainable land management and describe the impact reached and challenges faced	**Tanzania:** 1. Accelerated Food Security (AFSP) and Agricultural Sector Development Programme (ASDP) 2. HIMA project in Iringa Impacts i. Some farmers do prepare and apply compost to compensate low level of inorganic fertilizer use. ii. Contour ridges and agroforestry have reduced runoff and increase infiltration in the farmers' fields. iii. Where fodder was planted alongside the contour bunds runoff was minimal. **Challenges**

	i. Application of nitrogen fertilizer (Urea) without Phosphorus or Potassium as practiced by some farmers has led to accumulation of nitrate in the soil. ii. Low livestock ownership has led to limited adoption of farm yard manure. iii. Contours and agroforestry did not result in a significant increase in yields. iv. Contour construction was perceived as tiring and separate from routine land preparation. v. Few farmers adopted contours and many recently constructed ones were either destroyed or poorly maintained.
	Malawi 1. Farm Input Subsidy Program (FISP) 2. National Manure campaign 3. National Conservation Agriculture Task force (NCATF) 4. Agroforestry Support Program (AFSP) 5. Irrigation, Rural Livelihoods and Agricultural Development Project (IRLADP) 6. Soil and water management interventions **Impacts** i. Since the introduction of CA, the number of farmers adopting the technology has been increasing. A number of farmers have reported the benefits of CA in their fields. ii. An evaluation of the AFSP reported improvement in soil fertility in the target areas. iii. The AFSP reached 92 percent of 200,000 farmers targeted. iv. Various initiatives stated above have resulted in improved food security at household and national levels and diversified food groups. v. Increased land under irrigation in the country. vi. There is a political will on CA which is evidenced through continual dialogue between the parliamentary committee on agriculture and natural resources and the NCATF. **Challenges** i. Some farmers feel that CA is an input program not a farming systems program hence feel that CA without distributing inputs is not worthy adopting. ii. No availability of inputs and equipment for some programs. iii. Farmers setting fire on residues in fields of other farmers. iv. Coupon distribution for targeted fertilizer input subsidy program is riddled with malpractices.
	Zambia 1. Promotion of Fertiliser Trees in Eastern Zambia 2. Promotion of Conservation Agriculture **Impacts** i. The main benefit from the fertiliser tree fallows is increased yields. ii. ICRAF found that agroforestry-based soil management options were much more profitable than current farmers' practices. iii. To large extent **c**onservation farming practices improve soil fertility. iv. Though gains vary across locations and over time, evidence from central Zambia suggests that about 25% of observed gains under conservation farming stem from higher input use, another 25% from early planting, and about 50% of the yield difference stems from the interaction among other CF cultural practices, such as the retention of crop residue, the build-up of soil organic material and concentration of nutrients in the basins, and the water harvesting effects of the basins during the sporadic rainfall common in semi-arid zones of Africa

<table>
<tr><td></td><td>(Haggblade and Tembo, 2003).
v. Essentially conservation farming enables even the smallest, most cash-constrained Zambian farm households to achieve yield gains.

Challenges
i. Low uptake of fertilizer trees by farmers.
ii. Low adoption of conservation agriculture by the small-scale farmers.</td></tr>
<tr><td rowspan="3">Activity 4.2: To evaluate the policies related to the dissemination of best crop, soil, and water management options and access to the inputs required for implementing these options</td><td>Tanzania

i) Tanzania Development Vision (TDV) 2025
ii) Agricultural Land and Livestock Policy (1997)
iii) Agricultural policy (1983)
iv) National Strategy for Growth and Reduction of Poverty (NSGRP) June 2005
v) Agricultural Sector Development Strategies (ASDS) 2001
vi) Rural Development Policy (2001)</td></tr>
<tr><td>Malawi
i. A New Agricultural Policy – Developed in 2005.
ii. National Irrigation Policy and Development Strategy – Developed in 2000.
iii. National Water Policy – Developed in 2005.
iv. Agricultural Extension Policy.
v. Crop Production Policy.</td></tr>
<tr><td>Zambia
i. National Agricultural Policy.
ii. Irrigation Development and Support.
iii. Agricultural Infrastructure and Land Development.
iv. Agricultural Services and Technology Development.
v. Agricultural Marketing, Trade and Agribusiness Development.
vi. Cooperatives Development.</td></tr>
<tr><td rowspan="3">Activity 4.3: To assess the dissemination and promotion approaches used by the various extension partners operating and targeting of interventions aiming at agricultural intensification in the target areas</td><td>Tanzania
i. Farmer field schools.
ii. Training/study excursions of farmers’ and extension staff
iii. To create awareness (workshops, field visits, Farmer exhibition shows, TV and radio)
iv. Farmer Research Groups (FRG)
v. Demonstration plots
vi. Promoting Farmer Innovation.
vii. Participatory Technology Development.</td></tr>
<tr><td>Malawi
i. Demand driven extension method
ii. Lead-farmer concept
iii. Training of trainers concept
iv. The study circle concept
v. Targeting approach
vi. Platforms utilization
vii. Meaningful demonstrations
viii. Media</td></tr>
<tr><td>Zambia
i. Infrastructure development and support to the extension services in eastern province Project.
ii. Participatory Village Development in Isolated Areas (PAVIDIA).
iii. Participatory Extension Approach (PEA).
iv. Farmer Field Schools (FFS).
v. Lead Farmer</td></tr>
</table>

Initiatives Evaluated

In this study the initiatives that were evaluated were those related to crop, soil and water management. These included:

i. Integrated soil fertility management related projects
ii. Soil and water conservation promotion programmes
iii. Agroforestry support programmes
iv. Farm input subsidy programmes
v. National manure campaigns
vi. Conservation agriculture programmes
vii. Irrigation programmes

Lessons learned

- The projects that are promoting the soil and water management programmes are, usually, not long enough for farmers to appreciate the benefits of the interventions being promoted. Usually interventions like CA, agroforestry, etc. take more than three farming season for full benefits in soil improvements to show up but by that time the project is phasing out leaving farmers in suspense on the benefits of the technology. This has resulted in low adoption.
- In Malawi the National Agriculture Policy is not yet developed hence poor coordination of interventions in the agricultural sector.
- Some government policies and strategies are outdated hence require updating to fit with current changes.
- There are a number of challenges that have been reported in relation to implementation of the initiatives. Further research into these challenges and possible ways of correcting for them is necessary.

Concluding remarks

The study has revealed that in all three countries policies and initiatives were put in place towards development, promotion and dissemination of crop, soil and water management options. Nevertheless, some policies and strategies need to be updated since they were developed a few years back and do not take into consideration recent developments. There are documented impacts of a lot of the initiatives that governments and partners are implementing. However, there also reported challenges that should not go unchecked if the targeted areas in Tanzania, Malawi and Zambia are successfully attain the objectives.

General recommendations

Best-bet technologies, learning materials and policies to get intensification moving forward are already existing. However, some of the policies need revising since they have not considered recent developments and changes. Technologies like fertilizer additions, agroforestry and conservation agriculture have been proven to increase crop yields and are profitable to the farmers. Agroforestry and Conservation agriculture have proved to also increase soil C and conserve soil water.

It is notable that effort is needed to increase the number of agro-input dealers to be able to support the intensification effort. Similarly, there is need to expand the extension teams on the ground since scaling up towards intensification requires accompanying capacity building of farmers and farmer groups.

Land Degradation Surveillance Framework (LDSF) is an appropriate tool for assessing land and ecosystem health. Soil and ecological variables are needed to explain all variation of crop response, and to achieve this, there is need to add approximately 12 sentinel locations in the Africa Rising sites. Collaboration across CGIAR centres, NARS, and local organizations in critical.

Best bet options and practices need to be validated for scaling up to attain sustainable intensification under the Africa RISING. Evaluation and validation of these options should be done in terms of the agronomic, economic, and environmental performance of entry points such as right crop density, right spatial arrangement, time planting, weed management, appropriate varieties. This should be combined with the use of models and decision support tools for technology identification (site specific recommendations) and tradeoff analysis.

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Appendix 1: Best Bet Options for Maize and Rice in Tanzania

Category	**Maize, Southern Highlands**	**Maize, Eastern Zone**	**Maize, Central Zone**	**Maize, Northern Zone**	**Rice in Morogoro, Mbeya and Dodoma Regions**
Soil and Water Management	Ngolo or Matengo pits (Temu and Bisanda (1996) Integration of *Leucaena spp., Grevillea robusta, Faidherbia albida and Albizia spp.* with food crops (Minja, R. and East, R. 1996)	Growing fodder tree species (Kimenye and Bombom, (2009) Use of high value agroforestry trees species (Kimenye and Bombom, (2009)	Grass strips (Christiansson et al. 1993, Thomas and Mati 1999) Stone Lines (Lundgren and Taylor 1993) Trench farming (Critchley et al. 1999)	Growing fodder tree species (Kimenye and Bombom, (2009) Use of high value agroforestry trees species (Kimenye and Bombom, (2009) Minimum tillage (Elwell et al. 2000) Ridging and tie-ridging (Hatibu et al., 2000) Stony lines (Thomas and Mati 2000; Lundgren and Taylor 1993)	Rain water harvesting (Hatibu et al., 2000) Excavated Bunded Basins (majaluba) (Hatibu et al., 2000)
Soil fertility management	Integrated Soil Fertility Management (ISFM, 2012) including use of: Mineral fertilizers TSP, Minjingu Mazao, DAP and Minjingu Rock Phosphate Sulphur Conservation agriculture Green manure Composts Cereal legume cropping	Integrated Soil Fertility Management (ISFM, 2012) including use of all the following practices: Mineral fertilizers N and P TSP, Minjingu Mazao, DAP and Minjingu Rock Phosphate Sulphur Green manures Composts Use of green	Integrated Soil Fertility Management (ISFM, 2012) including use of: Mineral fertilizers (Marandu *et al.,* 2009) N and P TSP, Minjingu Mazao, DAP and Minjingu Rock Phosphate Compost making and use (Mutunga and Critchley,	Integrated Soil Fertility Management (ISFM, 2012) including use of: Mineral fertilizers N and P TSP, Minjingu Mazao, DAP and Minjingu Rock Phosphate Green manures Composts Use of green manure (local shrub,	Integrated Soil Fertility Management (ISFM, 2012) including use of: Mineral fertilizers N and P TSP, Minjingu Mazao, DAP and Minjingu Rock Phosphate

	system Combination of P, N and farm yard manure (Kamasho, 1997)	manure (local Shrub, *Vernionia subligera* (tughutu)	2001)	*Vernionia subligera* (tughutu)	
Crop management	Use of hybrids (CG4142, CG4141, H632, H614 &H6302) + mineral fertilizers (Kamasho, 1997)	Legume rotations (Lablab or Pigeon peas/rice rotations) (Ley and Ikerra 2005; Ikerra and Kalumuna, 2008; Mzimbili *et al.,* 2012) Cereal/legume intercropping (Ikerra and Kalumuna, 2008).	Use of high value agroforestry trees species (Kimenye and Bombom, (2009) Cereal Legume intercropping (Cowpeas, pigeon peas, lablab)	Maize/legume intercropping (lablab, pigeon peas) (Shetto, R and Owenya, M. 2007) The Mother/Baby Trial Design (Speeding up crop improvement in partnership with farmers) (Kimenye and Bombom, (2009)	Improved seed varieties (SARO, NERICA)

Appendix 2: Options identified for Malawi and Zambia sites and their adoption potential

Option	Adoption Potential
1. Legume rotations and intercropping cereals with legumes, such as *Cajanus cajan*, soybeans, groundnuts and the common bean	• Adoption of "best bet" legume technologies appear likely to remain low unless input (seed) and output (harvest) markets are improved. Eg Need for more processing enterprises to increase legume absorption by the market. • Many farmers claim to recognise the merits offered by legumes in improving soil fertility, they often accord higher priority to food security and income generation • There is competition of legumes with other crops for limited resources – land, labour and cash
2. Incorporation of crop residue into the soil, application of compost manure, green manures, and farmyard manure (cattle, sheep, goat and chicken)	• Farmyard manure is not widely available because most farmers do not have livestock (cattle and small livestock). This is despite that recommended application rates are often high: 10-15t/ha/yr and sometimes up to 40t/ha • Farmers value quantity of manure more than quality • Low manure availability problems cannot be addressed through increasing its use efficiency eg consistent placement of manure in planting hole instead of the traditional broadcasting • For high yielding maize, manure alone cannot supply the required N, esp in clay soils where mineralisation if often lower than in sandy soils.
3. Systematic interplanting of maize with *Faiderbia albida*	• Limited by the fact that it takes long to realise the benefits (up to 10 years) with tree establishment also taking long • Farmers want immediate benefits and are not that patient
4. Relay cropping/hedgerow intercropping or alley farming)	• N-fixing trees, shrubs or legumes such as Sebania sesban, Tephrosia vogelii, Crotalaria or perennial pigeon pea (Cajanus cajan) are grown as annuals and planted 3-6 weeks after the food crop. • Sunnhemp *(Crotalaria juncea)* is an attractive intercrop with either maize or cotton with good prices of US$2.5/kg in Zambia • Competition maybe high with the main crop as it grows vigorously, leading a yield depression of the main crop. Relay plant it at least 6 weeks after maize planting • Relay cropping is suitable fro areas of high population density and small farm sizes because it does not require farmers to sacrifice land to fallow. The disadvantage of this system is that the trees are felled and must therefore be replanted each year. Furthermore, the technology relies on late-season rainfall in order for the trees to become fully established.
5. Improved fallows using fast growing N fixing tree species that also produce a lot of biomass (e.g., *Tephrosia vogelii, Sesbania sesban,* or *Cajanus cajan)* (Ikerra *et al.*, 2001).	• Can be used to produce high quality manure by supplementing livestock feed with nutrient-rich fodder eg high P-content produced in dairy cattle fed with *Calliandra calothrysus* • Adoption of agroforestry technologies such as fertiliser tree fallows negatively affected by Institutional and government policy issues such as:

	- Fertiliser subsidies (affects profitability and adoption potential) - Property rights and customary practices such as bush-fire setting and free grazing which can be resolved by local leadership. - Non-food legumes unlikely to be widely accepted. • Presence of agroforestry supporting institutions; the capacity and commitment of Gvt agric extension staff; access to infrastructure such as roads and markets.
6. Promotion of conservation agriculture in maize-based systems -use of hand-hoe -magoye ripper+fertiliser or organic manure threat -Rotations with crop legumes -Weed control -Direct seeding – dibble stick; fitarelli	• Higher weed pressure under CA • Success hinged on herbicide use which also requires training, extension advice, availability of herbicides and the applicators. • Cotton growing areas of Malawi and Zambia more favourable for CA adoption because: - farmers are already familiar with the use of chemicals and herbicides, - no tillage and direct seeding using dibble stick is easier and - cotton companies provide loans for purchase of fertilizer and pesticides to farmers – some of the inputs could be in CA plots • Maintaining mulch is constrained by land tenure system – communal grazing in dry season, which requires community awareness and setting local bye-laws, bush fires and hosting pests. • All year round retention of crop residues as surface mulch competes with use as livestock feed in the dry season. In central Malawi, retention of crop residues hampered by fears of termites, rodents hunting, bushfires, fuelwood, roofing material etc • Demand-driven extension where farmers are expected to contribute towards the cost of extension does not support new techniques such as CA. • Local agro-dealer that sell inputs such as maize seed, fertilizers and herbicides are available in Malawi and Zambia but markets to sell their agricultural produce are not available. Even when the cost-benefit analysis at farm level indicates economic benefits, farmers may lack the opportunity to purchase inputs ahead of the cropping season, or lack the cash to invest. • Cover crops

Appendix 3: Training and Extension material

Item	Title/Type of Material	Year released	Authors	Organisation
1	Agroforestry Options Manual	2006	Liyunga K, Matakala P, Chintu R, Joao C, Fernando, Sileshi G, Aknnifesi FK and Ajayi OC	ICRAF/World Agroforestry Centre
2	Gliricidia – maize intercropping system; An extension trainers guide	2006	Aknnifesi FA,Nyirong J, Cullen TM, Matakala P, Sileshi G, Ajayi OC and Makumba	
3	Fodder shrubs for Dairy Farmers in East Africa – extension manual	ud	Wambug C, Franzel S, Cordero J, Stewart J	
4	How to manage a Gliricidia – Maize intercrop (flyer)	ud	Nyirongo J, Wolf, J	
5	Establishment and managing a Gliricidia Fallow: from transplanting to harvest of tree biomass (Manual)	2004	World agroforestry Centre (ICRAF) SA	
6	The Problem of Soil and Land Degradation. Bulletin No. 1.	2010	Thierfelder C and Wall P C	CIMMYT
7	Conservation Agriculture – a Sustainable System. Bulletin No. 2	2010	Thierfelder C and Wall P C	
8	The Role and Importance of Residues. Bulletin No. 3	2010	Thierfelder C and Wall P C	
9	The Importance of Crop Rotations. Bulletin No. 4	2010	Thierfelder C and Wall P C	
10	Manual and Animal Traction Seeding Systems in Conservation Agriculture. Bulletin No. 5	2010	Thierfelder C and Wall P C	
11	Weed Control in Smallholder Conservation Agriculture. Bulletin No. 6	2010	Thierfelder C and Wall P C	
12	Chemical Weed Control and Field Calibration of Knapsack Sprayers. Bulletin No. 7	2011	Thierfelder C and Mupangwa W	
13	Managing Conservation Agriculture (CA) Demonstration Plots	2011	Thierfelder C and Mupangwa W	
14	Implementing Conservation Agriculture (CA) on Farmers' Fields	2011	Thierfelder C and Mupangwa W	
15	Calibration of Animal Traction Direct Planters	2011	Thierfelder C and Mupangwa W	
16	Calibration and Operation of Jab Planters	2011	Thierfelder C and Mupangwa W	

17	Grain Legume Processing Handbook: Value Addition to Bean, Cowpea, Groundnut and Soybean by Small-Scale African Farmers (Also translated into Kiswahili)	2011	Woomer, P et al.	CIAT (N2Africa project)
18	Biological Nitrogen Fixation and Grain Legume Enterprise: Guideline for N2Africa Lead Farmers	2010	Woomer, P	
19	Biological Nitrogen Fixation and Grain Legume Enterprise: Guidelines for N2Africa Master Farmers	2010	Woomer, P	
20	Master Farmer Training in Biological Nitrogen Fixation and Grain Legume Enterprise	2010	Woomer, P	
21	N2Africa Master Farmer Training manual.	2010	Anonymous	
22	Agro Dealers Training: Reference Manual.	2012	Musyoka, J. M.	
23	Advancing Technical Skills in Rhizobiology: A two week training course conducted in the East and Central Africa Hub of the N2Africa Project.	ud	Anonymous	TSBF - CIAT
24	A manual on integrated soil fertility management in Africa. African Crop Science Conference Proceedings, vol. 9, 357 - 363	2009	Sanginga N and Woomer P	
25	Area-specific fertilizer recommendations for hybrid maize grown by Malawian smallholders: a manual for agricultural extension personnel	1999	Benson, T.	Ministry of Agriculture and Irrigation. Government of Malawi.
26	Conservation agriculture: A manual for farmers and extension workers in Africa.	2005	Anonymous	International Institute of Rural Reconstruction, Nairobi; African Conservation Tillage Network, Harare
27	Mitigating the impact of HIV/AIDS by labour saving technologies. Information series No. 9	2004	Steiner, KG, Kienzle, J.	African Conservation Tillage Network

28	Achieving Sustained Gains in the Food Security of Vulnerable Households. Briefing Note 1	2006	Anonymous	ICRISAT
29	Building Sustainable Fertilizer Delivery Systems for Drought-Prone Regions. Briefing Note 2	2006	Anonymous	
30	Do Seed Fairs Improve Food Security and Strengthen Rural Markets? Briefing Note 3	2006	Anonymous	
31	Is Conservation Agriculture an Option for Vulnerable Households? Briefing Note 4	2006	Anonymous	
32	Quantifying Vulnerability – Accurately Reaching Those Who Are Most in Need. Briefing Note 5	2006	Anonymous	
33	Grow More Grain Using Planting Basins. Briefing Note 6	2006	Anonymous	
34	Agricultural Technology Transfer under Relief and Recovery Programs in Zimbabwe: Are NGOs Meeting the Challenge? Briefing Note 7	2006	Anonymous	
35	How To Use Small Quantities of Nitrogen Fertilizer. Poster	2006	Anonymous	

ud = undated