Agricultural Water Management Interventions (AWMI) for Sustainable Agricultural Intensification (SAI) in the Chinyanja Triangle

A Discussion of Potentially Applicable AWMI and Other General 'Brightspots'

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About the Report

This report is a discussion of promising agricultural water management intervention (AWMI) options for sustainable agricultural intensification (SAI) applicable to the Chinyanja Triangle straddling Malawi, Mozambique and Zambia. The main purpose of the report is to identify agricultural water management (AWM) interventions, with a focus on irrigation, but also soil and water conservation, conservation agriculture practices and other bright sports that are suitable for sustainable agricultural intensification (SAI) for rural livelihoods improvements in the Chinyanja Triangle.

The report is part of IWMI's contribution to the Drylands Systems Program whose goal is to identify and develop resilient, diversified and more productive combinations of crop, livestock, rangeland, aquatic and agroforestry systems that increase productivity, reduce hunger and malnutrition, and improve quality of life for the rural poor. The applicable strategic theme is the original Strategic Research Theme 3 (SRT3) on "Sustainable Intensification and Market Linkages". The Chinyanja Triangle is considered poor and thus has a high potential to benefit from the application of locally appropriate technologies, such as irrigation, to reduce poverty and improve rural livelihoods.

The methodology applied comprised, firstly, itemising all agricultural water management interventions that could potentially be applicable to smallholder irrigated, farming as well as rainfed agriculture in the Chinyanja Triangle. The listing was deliberately broad based so as to try and capture all possible interventions. To better manage the available possibilities, the listing was based on water lifting technologies (pumped or gravity), and scale of operation in terms of size (from large to small areas commanded and that held by individual farmers). Secondly, an extensive literature review was undertaken using the internet, irrigation books, journal articles, reports, grey literature, study reports, opinion pieces, postgraduate theses, concept notes and others. For the internet, the searches were directed by key phrases and words such as; agricultural water management, sustainable agricultural intensification, technology uptake, rainfed agriculture, conservation agriculture, up scaling pathway, just to mention a few. As would be expected, these searches generated a substantial amount of interesting literature material, which in itself led to more literature sources. The literature was then packaged according to the main report areas into which it fitted based on a previously agreed Table of Contents (e.g., large scale commercial irrigation, irrigation costs, conservation agriculture, etc). The literature was then analysed and synthesised with respect to its contribution to the specific section of the report, but more importantly, relevance and potential applicability to the Chinyanja Triangle agricultural interventions, i.e., prospects for sustainable agricultural interventions. At each and every point in the analysis, effort is made to provide reference literature that supports the key position being advocated for.

From the 18 or so agricultural water management interventions discussed a list of six best bet options is derived. The selection of these six interventions is based on; the scale of interventions (mainly small scale), the existence and recommendations of previous studies on possible interventions (namely the work of Mutiro and Lautze (2014) and Daka (2006)), the potential for sustainable uptake based on what is already practiced in the area (as evidenced by literature), the possibility of realising positive results with minimal capital and operational investment (based on literature). The selection of these six does not preclude researching or trying out the other interventions under the Drylands Systems Program. Finally, the report highlights research issues that may need follow-up depending on the thrust of the IWMI researchers. The research topics identified relate mainly to the options identified for the Chinyanja Triangle, but also to general knowledge gaps on AWMI issues in the area.

SUMMARY

The rural communities of the Chinyanja Triangle are considered among some of the poorest in the world and lack access to food for 3 to 4 months per year due to the rainfall variability manifested in drought or floods. These communities can benefit from the application of locally appropriate technologies, such as irrigation, to stabilise agricultural production and consequently improve their food security situation as well as their livelihood. IWMI is conducting research in the area under the Drylands Systems Program, and of particular interest is Strategic Research Theme 3 on "Sustainable intensification and Market Linkages". As part of this research, there is a need to explore possible agricultural water management interventions (AWMI) that could be used to sustainably intensify agricultural production as well as flag research issues.

Drawing on various sources of literature from internet searches and other sources such as journal articles and books, this report discusses potentially applicable AWMI for sustainable agricultural intensification (SAI) applicable to the Chinyanja Triangle. A summary of the agricultural water management technologies and practices currently found in the area is given including the adoption and perceived impacts. In summary the identified technologies are for small scale production and their adoption and impact is mixed, but some hold potential. The report then discusses all possible AWMI starting with large scale irrigation intervention down to drip kit irrigation and soil and water conservation practices (including conservation agriculture). After each intervention is discussed, prospects for SAI using that AWMI in the Chinyanja Triangle are highlighted. The AWMI are compared in a summary table in the Appendix with respect key advantages and disadvantages and the prospects for SAI.

Based on literature review, scale of operation, technologies currently practiced in the area, and the potential for uptake with low development and operation investment, six AWMI best bet options are identified. These comprise; small scale irrigation with river diversions, smallholder irrigation with motorised pumping, dambo irrigation farming, drip kits (to include bucket and drum kits) with treadle pumps in areas with shallow water tables, small reservoirs, and soil and water conservation technologies including conservation practices. The selection of a particular AWMI (e.g., smallholder irrigation) does not necessarily preclude the selection of another AWMI in this group of six (e.g., drip kits). For each of these, the envisaged practical up-scaling pathways are discussed. Most of the up-scaling pathways require that agricultural production be linked to markets for the produce so that the systems are self-sustaining in terms of operation costs.

The report highlights research issues that need to be explored. These include; systems approach constraints analysis to SAI in the area, assessment of farmer attributes for enhanced technology uptake, analysis of development opportunities including and beyond AWMI, assessment of gender-based constraints to accessing new opportunities and options, analysis of the suitability of proposed best bet options in the area, research into acceptability and adoptability of drip kit technology in the Chinyanja Triangle, and research exercise to apply the Targeting AGwater Management Interventions (TAGMI) model to the technologies that have been identified for the Chinyanja Triangle to try and find out which ones have a high likelihood of succeeding if implemented in the area.

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Acronyms Used

ATA	Agricultural Transformation Agency
AWM	Agricultural Water Management
AWMI	Agricultural Water Management Intervention
CA	Conservation Agriculture
CAADP	Comprehensive Africa Agriculture Development Plan
CPWF	Challenge Programme on Water for Food
CSA	Climate Smart Agriculture
DFID	Department for International Development
DSF	Decision Support Framework
EGS	Ecosystem Goods and Services
ERWH	Ex-field Rainwater Harvesting
FAO	Food and Agricultural Organisation (of the United Nations)
GCM	General Circulation Model
IDE	International Development Enterprise
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IMAWESA	Improved Management of Agricultural Water in East and Southern Africa
IMC	Irrigation Management Committee
IARS	Integrated Agricultural Systems Research
IPCC	Intergovernmental Panel on Climate Change
IRWH	Infield Rainwater Harvesting
IWMI	International Water Management Institute
LISA	Low Input Sustainable Agriculture (also called LEISA - Low External Input Sustainable Agriculture)
LSCI	Large Scale Commercial Irrigation
MTI	Moistube Irrigation
NEPAD	New Partnership for African Development

PIPA	Participatory Impact Pathways Analysis
PRDA	Participatory Rapid Diagnostic and Action
RWH	Rainwater Harvesting
SAI	Sustainable Agricultural Intensification
SCI	System of Crop Intensification
SEI	Stockholm Environment Institute
SFMI	System of Finger Millet Intensification
SIA	Sustainable Intensification of Agriculture
SIS	Smallholder Irrigation Schemes
SRI	System of Rice Intensification
SRT3	Strategic Research Theme #3
STI	System of *Tef* Intensification
SWI	System of Wheat Intensification
SWNM	Soil Water and Nutrient Management
TAGMI	Targeting AGwater Management Interventions
TOC	Theory of Change
UNDP	United Nations Development Programme
WFE	Water-Food-Energy
WOCAT	World Overview of Conservation Approaches and Technologies
WOT	Watershed Organisation Trust
WUA	Water Users Association

1. Introduction and Background

1.1 The Chinyanja Triangle and its Significance

The Chinyanja Triangle is found in the Zambezi River Basin and includes central Mozambique (Tete province), southern and central parts of Malawi, and the eastern provinces of Zambia. The area is inhabited by Chinyanja speaking people who share a generally similar history, language and culture (Tilahun Amede, *et al*., 2014). In excess of 90% of the rural population of Chinyanja Triangle depend on rainfed agriculture as part of their livelihood strategy, and the farming system is predominantly crop based, producing crops such as maize, groundnuts, and small grains like sorghum and millet (Myburgh and Brown, 2006). There is also cassava production in the area for both food and cash generation purposes (Kambewa, 2010). Crop-livestock farming is also important in the area. Typical farming subsystems comprise; maize-cassava-fish-based farming, sorghum-millet-livestock farming and livestock-based farming.

More details on the background to the Chinyanja Triangle (e.g., land area, rainfall, geography, soils, population densities, etc) can be found in the publication by Amede *et al*., (2014). At this point the important aspects to mention are that the people of Chinyanja Triangle suffer from challenges such as persistent and recurrent drought (which often alternate with excessive rain and floods) (Kambewa, 2010). This unpredictable rainfall and the dominance of rainfed agriculture makes the area very vulnerable in terms of food security. Agricultural production levels are low, crop yields are well below expected levels and land and water productivity are quite low. People of the Chinyanja Triangle are some of the poorest in the world and the region is food insecure with 60 to 85% of the rural households lacking access to food for 3 to 4 months a year (Akinnifesi *et al*., 2006; Twomlow *et al*. 2008) and thus depending on food aid. Furthermore, the communities are characterised by poor access to markets, limited institutional support, lack of investment, and overall deterioration of livelihoods (Amede *et al*. 2014).

Due to the vulnerability of the communities in the Chinyanja Triangle because of their over-dependence on rainfed agriculture, the area is well positioned to benefit from interventions that are pro-poor and sustainable in the long run. Since agriculture is a major livelihood strategy with water being one of the main constraints to agricultural production, sustainable agricultural interventions that are based on agricultural water management, including irrigation development, offer prospects for improving the welfare (food security and economic development) of the rural populations of the Chinyanja Triangle across the three countries. Indeed, irrigation development is considered as a possible strategy for resource poor smallholder farmers in the area to get out of poverty by shifting towards market oriented agriculture (FAO, 1997) by growing high value crops. It is argued that investments in AWM can reduce rural poverty through accelerating broad based agricultural growth. (According to FAO (1997), in the Chinyanja Triangle, irrigated agriculture contributes to less than 10% of the produce. Any agricultural water management and irrigation interventions proposed and promoted must be embedded in the farming systems obtaining in the area.

1.2 Agricultural Water Management Interventions (AWMI)

Agricultural water management (AWM) is normally taken to mean the range of technologies and practices whose aim or objective is to ensure that adequate water is available in the crop root zone for successful crop growth and production (Merrey *et al*., 2006). This would include the capture, storage and drainage of any water used for agriculture. The Improved Management of Agricultural Water in East and Southern Africa (IMAWESA) project conveniently defined AWM as the deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes, the source of water would include direct rain as well as water supplied from surface and underground sources (Mati, 2007). AWM is therefore the management of all the water put into agriculture (field crops, tree crops and livestock) in the continuum from rainfed systems to irrigated agriculture. It includes agronomy, soil and water conservation, rainwater harvesting, irrigation and drainage, interventions such as integrated watershed management and all relevant aspects of management of water and land. Because these technologies and practices encompass rainfed and irrigated agriculture it means by extension that AWM is important for any successful agricultural production.

The technologies and practices covered in AWM can, for ease of analysis, be divided into three broad categories that comprise; technologies for water control and storage, technologies for water lifting and conveyancing, and technologies for field water application (Regassa Namara *et al*., nd). It is interesting to note that Merrey and Sally (2008) chose to call or term these micro-agricultural water management technologies (micro-AWM). For all practical purposes, there is really no difference between the two terms – AWM and micro-AWM, the latter seems to emphasise size and scale of operation (smallholder and small scale). Technologies for field water application cover the irrigation water application methods, from flood (surface) irrigation, through pressurised sprinkler irrigation and drip or trickle irrigation all the way to practices such as subsurface irrigation and pitcher irrigation using an assortment of equipment such as clay pots, clay pipes and bamboo sticks pipes. Technologies for water lifting and conveyancing include pumping methods that also range from simple contraptions like the bucket or gardening can, through human powered treadle pumps all the way to include motorized and electrics pumps. Conveyancing technologies could include piped systems, but for smallholder farmers these tend to be canal systems – lined or unlined – from source through to infield distribution. Pumping technology has been found to have a strong bearing on the success of irrigated related AWM because of the attendant operational costs of fuel or electricity. Technologies for water control and storage include; conservation agriculture practices, in situ soil and water conservation technologies, ex-situ water harvesting and storage, (small) storage dams and tanks, rooftop rainwater harvesting (with storage tanks), underground tanks (for surface runoff capturing), and ground water sources (shallow wells and boreholes).

The above categorisations are not prescriptive, and to a large extent AWM can be taken as combinations of the above depending on location and conditions that exist at a particular place. Indeed, in the ensuing discussion in this paper, the irrigation based AWM practices combine water application methods with specific water lifting technologies to form common combinations that are then discussed from the perspective of sustainable agricultural intensification for the Chinyanja Triangle (see Section 3).

1.3 The Concept of Sustainable Agricultural Intensifications (SAI)

Sustainable agriculture (or agricultural) intensification (SAI) (also termed sustainable intensification of agricultural production, SIA) derives from the need to intensify production (e.g., producing more with less water and land) in a sustainable manner using an agro-ecological approach and through socio-economics and institutions, and all key stakeholders should be involved from the beginning of any interventions using participatory approaches. According to Conway (2014), SAI provides a means for tackling hunger, malnutrition and poverty while at the same time protecting and improving the environmental base. Successful SAI requires human ingenuity, creativity and innovation, given the severe resource constraints and global warming (Conway, 2014) faced by mankind. The demand to be food secure, reduce poverty and promote economic development for agro-based rural economies requires that agricultural production (output) increase, and such increases can be achieved through; intensifying crop production on land already under cultivation but at the same time preserving ecosystem goods and services and preventing further land degradation, as well as sustainably expanding the area that is cropped (Dreschel, *et al*., 2014). Concerns raised with respect to this intensification is whether it is possible to do so, given the following; declining growth rates in crop yields in some places or locations, increased land degradation due to anthropogenic and climate change driven factors, increasing competition for water resources by other sectors and users, declining soil fertility levels, climate change, and the incessant pressure on biodiversity and ecological services.

Despite the positive tone, it is also argued that there is some ambiguity around what is really meant by SAI and how it can be implemented. Some argue that SAI suffers from contradictions and ambiguities on how it can be applied to promote and defend disparate positions on how to foster and approach agricultural development (Garnett and Godfray, 2012). At times SAI is seen as being at cross purpose and ignores values, goals and knowledge of (local) farmers in many parts of the world as it focuses on progress and productivity as defined by those on the 'outside' of local farming communities. Sometimes by interpretation, it is assumed that SAI involves low input sustainable agriculture (LISA) systems which, in reality, are not necessarily sustainable without recourse to , for example, inorganic fertilisers as soil fertility mining occurs when farmers operate at levels that would enable them to produce enough crops for food or cash (Reardon, *et al*., 1998; Reardon and Barett, 2001).

When SAI is practiced, there are some trade-offs that have to be contended with. The key tenets of SAI (intensify production, agro-ecological approach and all stakeholder participation) have corollaries that turn out to be trade-offs that may minimise the intended benefits. Intensified production can result in resource depletion (e.g., soil fertility mining), competition for resources (e.g., water and land), short-term profit motive (for the success of SAI), SAI technology choices may not necessarily be productive enough to sustain the farmer (cash or food crop production), and the participation of all stakeholder tends to delay the implementation of projects (as consensus is sought to placate all) (Reardon, et al., 1998). So in order for SAI to succeed it may be necessary to follow the capital intensive approach, as opposed to labour-intensive. This in itself would be contrary to the key elements of SAI. Another example is that of conservation agricultural (CA) practices where there is the need to leave mulch on the ground, but in mixed crop-livestock systems this mulch is used as animal feed in winter, lack of tilling the land leads to severe weed infestation problems, and small land holding sizes work against proper crop rotations (Giller, *et al*., 2009).

If and when SAI is practiced it must be linked to an integrated systems' approach. The systems' approach to agricultural research for development, as espoused by the CGIAR, effectively 'incorporates the constellation of social, economic, and institutional factors controlling the adoption of new innovations and technologies' (see CGIAR Dryland Systems website). Underdeveloped areas like the Chinyanja Triangle face a wide array of severe physical, social and economic constraints (from degradation and water scarcity to weak governance, poor access to markets, and a limited capacity to deliver new innovations and technologies to farmers). SAI approaches must therefore be applied within the full context of an understanding of the constraints militating against uptake of technologies and interventions meant to uplift the rural livelihoods of people in the area.

Generally, it is agreed that sustainable intensification (SI) strategies need to be followed up or tried out by the agricultural sectors, if food security is to be achieved on a global scale (Abraham, *et al*., 2014). Researchers and practitioners recommend that these intensification approaches must not depend on intensive external inputs to get increased output because of the attendant increased economic and environmental costs. Some systems of sustainable intensification have arisen and have been documented and are worth mentioning here so that they may serve as possible examples for the Chinyanja Triangle interventions, were possible. The most common of these are the systems of crop intensification (SCI), deriving from work done in Africa and Asia. These SCI have been found to increase productivity of water, land, seeds, labour and capital resources that farmers can invest to produce a wide range of field crops (WOT, 2013).

The first of these SCI is the system of rice intensification (SRI) that has been tried in Asia, Madagascar, East and Southern Africa as well as West Africa (Stoop, *et al.,* 2002; Uphoff and Randriamiharisoa, 2002) whose key components comprise; establishment of healthy plants, reduction in crop intensity to give each plant more room to grow, managing soil fertility and soil health through application of organic matter and proper aeration, and application of water in a manner that enhances plant root and soil microbial proliferation. SRI will find application in the rice growing areas of the Chinyanja Triangle, especially those based on *dambo* farming. Another one of SCI is the system of finger millet intensification (SFMI) practiced in India which promotes the use of widely spaced transplanted seedlings accompanied with appropriate soil, water and nutrient management (SWNM). Yield results from SFMI practices have shown yields increasing from 1 ton/ha for traditional practices to 3 or more tons/ha for SFMI (PRADAN, 2012). Also from India is the SCI called system of wheat intensification (SWI) whereby under irrigated conditions farmers wheat yields increased by 80% to 100% and by up to 60% to 80% for non-irrigated wheat (Prasad, 2008). Lastly from Ethiopia comes the system of *tef* (*Eragrostis tef*) intensification (STI) which involves transplanting young *tef* seedlings and spacing them widely and then applying organic fertilisers (ATA, 2012). Under STI, *tef* yields were found to increase to 3 to 5 tons/ha, and given such increases the Ethiopian government is said to have increased the area under STI management to over 1 million ha in 203/14 season with an aim to increase this to 2.5 million ha in 2014/15 season.

The lessons from the above discussion are that SCI offers opportunities for smallholder farmers in the Chinyanja Triangle to intensify agricultural production in a sustainable way. As is always the case, the idea is to learn and adapt these SCI practices to the crops grown and conditions found in the area.

Farmers grow small grains crops such as millet and sorghum and these can benefit from SFMI practices, over and above the AWM interventions proposed.

1.4 Resource Conserving Agricultural Production

Resource conserving agricultural production is needed now because 'doing more of the same will not work' simply because agriculture in the current century needs to contend with massive changes in the physical and institutional environment (Uphoff, 2012). Some of these changes include; declining arable land per capita (meaning land extensive practices are not sustainable), water supply to farmers for agricultural production is becoming scarce and less reliable, higher energy costs imply energy intensive production practices will not be financially and economical viable, the resurgence of concerns for the environment mean some of the intensive external input agricultural practices will not be acceptable to society, pest and diseases and their resistance to agrochemicals are likely to increase, climate change will call for climate smart agriculture (CSA), and the capabilities of governments to deal with the emerging constraints maybe diminishing.

The shrinking resource base available for agricultural production implies that future production be resource conserving through intensification (not intensification of input use, as has been the case in the past) of management involving more knowledge and skills. Intensification of management seeks to obtain more output from limited input use (Uphoff, 2012). In the strictest sense it is found that resource conserving agricultural production is closely related to sustainable agricultural intensification.

As the population in the Chinyanja Triangle increases and agricultural production resources such as water and land diminish or are fiercely competed for, practicing resource conserving agriculture will be the way to go. Such production would need to be tailored to the practices found in the Chinyanja Triangle and the resource base of the rural population in the area within the context of a systems approach.

2. Literature Review on Agricultural Water Management Interventions (AWMI) in the Chinyanja Triangle

In a recent review, agricultural water management interventions (AWMI) for the Chinyanja Triangle were documented in an effort to identify what is known and areas where 'knowledge is deep, thin or absent' and this had the short to medium term goal of informing research in the area (Mutiro and Lautze, 2014). That review proceeded by way of literature search of documents of all types (as hard copies, internet search as well as web searches of organisations involved in rural development or had been active in the Chinyanja Triangle). In total the review looked at 32 documents on AWMI in the three countries, i.e., Mozambique, Malawi and Zambia. The following sections of this report summarise the key findings of that review. The summary forms a base upon which further exploration of irrigation related AWMI are considered and prospects for SAI in the Chinyanja Triangle discussed (see Section 3).

2.1 Agricultural Water Management Technologies Identified in Practice

The Mutiro and Lautze (2014) review identified 6 AWM technologies in the Chinyanja Traingle. These comprised; treadle pumps, drip (irrigation) kits, motorised pumps, river diversion into canals, bucket (irrigation) systems, dambo cultivation, clay pot (pitcher) irrigation, use of residual moisture, small reservoirs (dams) or earth dams, and conservation agricultural practices. The list of identified AWM technologies agrees to a large extent with a report from Daka (2006) which also identified the same types of technologies and practices in Zambia. The listing gives an indication of possible irrigated related AWMI that are applicable in the Chinyanja Triangle. What is apparent from the list is that the technologies are basically geared towards smallholder farming. There are many historical reasons as to why this is the case, but as we move forward, the discussion in this report will strive to be all encompassing and look at all irrigation related interventions, from large scale through to small scale.

2.2 Agricultural Water Management Technologies Adoption and Sustainability

An analysis of the adoption and sustainability of the identified AWM technologies and practices in the Chinyanja Triangle was also undertaken and the results were somewhat mixed regarding the success and sustainability of these (Mutiro and Lautze, 2014). In short the findings regarding adoption were as follows; treadle pumps had low adoption for various reasons (including labour demand and lack of spare parts), motorised pumps had a high adoption rate among the resource endowed farmers in the area, river diversions were found to be an old and tried technology although they suffered from poor infrastructure, dambo cultivation adoption was quite high in places like Malawi, the bucket system had a high adoption rate among the resource poor farmers, low cost drip irrigation systems adoption was mixed being good in countries like Malawi, and small reservoirs had poor adoption in places like Malawi.

Table 1: Comparison of technologies with respect to adoption and sustainability (from Mutiro and Lautze, 2014 draft report)

Technology	Adoption	Sustainability
Treadle Pumps	High adoption rate due to low operational costs and increase in yield and net farm income	Highly sustainable where labour is available.
River Diversion	High adoption rate due to low operation and maintenance costs.	Highly sustainable only in cases where there is improved infrastructure and water availability.
Motor pumps	Medium adoption rate due to high maintenance costs	Sustainability depends on availability of spare parts,
Drip irrigation (Drip kits)	Low adoption rate due to complexity of the system	Low sustainability due to limited training on the usage and maintenance.
Bucket system	High adoption rate due to low operational costs	Highly sustainable because it's cheaper.

Dambo cultivation	High adoption rate due to low operational costs and increase in yield and net farm income	Highly sustainable only if there is no over abstraction of water and soil erosion in the sub-catchment
Small reservoirs/ irrigation dams/ Earth Dams	Low adoption rate due to conflicts over usage and ownership.	Low sustainability due to conflicts over water usage and ownership

Adoption of AWM technologies is a complex process driven by many factors that have to do with the status of the farmers and the characteristics of the technology itself. More is said about adoption in this report later on with respect to the many irrigation related AWM interventions discussed.

2.3 Agricultural Water Management Real and Perceived Impacts

The Mutiro and Lautze (2014) report further attempted to quantify the impacts (positive or negative) of the various AWM technologies identified in the Chinyanja Triangle. What may not be clear from the report is whether the impacts are for real or perceived because when one looks at these, they read like advantages (positive) and disadvantages (negatives).

Table 2: Comparison on technologies with respect to impacts (from Mutiro and Lautze (2014) draft).

TECHNOLOGY	**IMPACTS**	
	Positive	**Negative**
Treadle Pumps	a) Increased cropping intensity b) Increased yield c) Increased net farm income d) Maintenance of food security e) Increased area under irrigation	a) Increased competition for water b) Over-abstraction of water c) Water conflicts due to increased competition for available water d) Labour intensive
River Diversion	a) Increased cropping intensity b) Increased yield c) Increased net farm income	a) Increased competition for water b) Over-abstraction of water c) Water conflicts due to increased competition for available water
Motor pumps	a) Increased cropping intensity b) Increased yield c) Increased net farm income	a) Increased carbon emissions b) Negative gross margin realised in some areas c) Over-abstraction of water
Drip irrigation (Drip kits)	a) Water saving b) Increased net farm income c) Increased yield	a) Labour intensive b) High failure rate
Bucket system	a) Increased cropping intensity b) Increased yield c) Increased net farm income d) Low operational costs	a) Labour intensive b) Time consuming hence farmers have less time to do other work
Dambo cultivation	a) Increased cropping intensity b) Increased yield	a) Over abstraction of water b) Lowering of the water table

	c) Increased net farm income d) Low operational costs	c) Distraction of biodiversity d) Increased competition among multiple users e) Over-exploitation of dambos
Small reservoirs/ irrigation dams/ Earth Dams	a) Increased area under irrigation as more water is available b) Increased cropping intensity c) Improved yields	a) Conflicts over water usage b) Conflicts over ownership of the dams

Admittedly, it is to be expected that these AWM technologies would have some positive impacts, and these would vary by location as well as in time, i.e., a technology or practice could have a positive impact in one place but not the other and also could have an impact early in the project cycle and then diminish with time. Typical examples are treadle pumps and drip kits that seemed to have been adopted and offered benefits when they were introduced but were soon abandoned once the supporting projects ended.

2.4 Agricultural Water Management Identified Gaps

The Mutiro and Lautze (2014) draft report ends with an informative prioritised summary of issues that (may) need further exploration or research in the Chinyanja Triangle. The summary includes such topical issues as; sustainability of the AWM technologies identified, water productivity analysis of informal irrigation, assessing the extent of water scarcity in the Chinyanja Triangle, evaluation of income and gross margins of various crop enterprises, comparing the impacts of informal and formal interventions (with respect to technology, food security, poverty alleviation, and economic development), issues of conflicts and their impacts on sustainability, and the comparison of operational and maintenance costs of diesel or petrol pumping compared to electric motor pumping. The research, if and when it goes ahead, will contribute toward answering the questions on how the AWM technologies can help in the developmental processes and outcome, and how scalable and out-scalable these are.

With the above summary from previous literature review on present technologies in the Chinyanja Triangle, the following sections discuss the prospects of diversification and SAI using irrigation related interventions.

3. Prospects for Diversification and Sustainable Agricultural Intensification Using Irrigation in the Chinyanja Triangle

The first question that may even be asked at this stage is ‘why irrigation-based AWM interventions for sustainable agricultural intensification leading to poverty reduction, food security and economic development in the Chinyanja Triangle? In the context of the initiative of the African Union (AU), New Partnerships of African Development (NEPAD), African countries pledged to spent 10% of the government budget on agriculture and the first of the Comprehensive Africa Agriculture Development Plan (CAADP) pillars is land and water development, with a major emphasis on the construction of irrigation systems. Admittedly, at US$5000 to US$20000 per ha, the development will not be cheap

(Svendsen, *et al*, 2011). Notwithstanding costs, irrigation is part of the national development agenda, so interventions based on irrigation will be within the policy frameworks of countries in the region. In a 2014 integrated modelling study looking at irrigation expansion potential in sub Saharan Africa for four smallholder irrigation technologies, namely, motor pumps, treadle pumps, communal river diversion and small reservoirs, Xie, *et al*., (2014) revealed a huge potential for profitable smallholder irrigation expansion. As an example they found that the expansion potential for motor pump irrigation was 30 million ha, for treadle pumps 24 million ha, for small reservoirs 22 million, and 20 million ha for communal river diversions. With such potential, it is well worth exploring irrigation based interventions for the Chinyanja Triangle.

Literature from the past (Hussain and Hanjra, 2004; Hussain, 2005), Hanjra and Gichuki (2008) and present (IFPRI, 2015) provides convincing evidence of the positive linkages between irrigation development and poverty reduction and food and nutrition security. Several pathways help irrigation development to reduce poverty, and these according to Hanjra, *et al* (2009) include the facts that; irrigation boosts crop output (through higher yields, higher cropping intensities, more cropped area and better returns from other production inputs like hybrid seeds and fertilisers), irrigation generates higher and more stable labour demand (due to additional labour requirements for initial construction and on-going maintenance or irrigation infrastructure), higher production and higher incomes make food available and affordable for the poor (due to a reliable supply of food, reduced food prices and improved purchasing power of the farmers), irrigation enables crop diversification by allowing farmers to divest from subsistence farming and move towards high value market driven crop production, increased agricultural productivity and incomes generate demand for on-farm goods and services and the local economy (thus starting growth multipliers with forward and backward linkages), irrigation reduces inter-temporal and seasonal variations in agricultural output, employment and prices (thus reducing poverty through income and output stabilisation), irrigation has positive effect on nutrition and health (due to more and stable food supply), irrigation infrastructure allows for multiple uses of water (e.g., for agriculture, domestic water provision, livestock watering, fishing, rural industries), and irrigation improves equity in favour of the poor (by distributing limited water resources and public investments among more members of society).

Recent publications have provided ample evidence that irrigation can be successful and can also assist in ensuring food and nutrition security. The publication by Mutiro and Lautze (2015) indicates that on average, irrigation schemes (59%) in Southern Africa can be considered as successful (this is quite good given the usual gloom and doom reports that critique (formal) irrigation development). The attendant drivers of this success were found to include; socio-institutional arrangements (management style), water application methods, cropping enterprises, financing arrangements and the geography of the area. The findings from the analysis, interestingly, seem to be advocating for increased irrigation development, the increased use of pressurised irrigation (sprinkler) and a reduction in flood (surface) irrigation. This is almost the opposite of what is generally promoted, i.e., use of flood irrigation as it is perceived to have low running costs. They conclude that these successes validate calls to increase irrigated agriculture in Southern Africa and highlights opportunities to strengthen the way in which future irrigation development should be undertaken. On the other hand the publication by Domenech (2015) admits that evidence linking irrigation and the various determinants of nutrition are somewhat scant on the ground. However, the paper does recommend that if irrigation development is being used to deal with nutrition problems in sub-Saharan Africa, then attention has to be paid toward some of the following factors; the goals of irrigation development must include food security and nutrition gains, irrigation interventions should promote food production that is nutrient-dense, multiple uses of irrigation water should be recognised, participation and empowerment of women in irrigation programmes must be promoted, and homestead food production (from low cost interventions) should be supported.

However it must also be mentioned that investments in irrigation alone are not sufficient for the elimination of poverty, i.e., investments that ensure or improve access to water are necessary but not necessarily sufficient for the elimination of poverty (Hanjra, et al., 2009).

As discussed in the previous sections, several AWMI were identified in a previous study (Mutiro and Lautze, 2014) for the Chinyanja Triangle. In this section the key focus of discussion is on highlighting the prospects for diversification and SAI using irrigation or irrigation related interventions. The tone of this discussion is not one of playing irrigation against rainfed agriculture (as tends to happen at time), but that of letting both these approaches complement each other to enhance rural livelihoods in systems perspective. Merrey and Sally (2008) argue that based on analysed data, investments to improve the productivity of rainfed agriculture will have higher payoffs in terms of poverty reduction, enhancing agricultural growth and food security in most sub-Saharan countries than would conventional irrigation investments. Falkenmark and Rockstrom (2004) state that it is not possible to mobilise adequate blue water for irrigation to meet the food security needs for sub-Saharan Africa in the next 20 years. AWM solutions accord an opportunity for specific communities in the study area to select or adopt specific practices that are applicable to conditions obtaining in these communities, thus debunking the myth of 'one size fits all' approach.

Extending on the above argument is the issue of scale of intervention – large scale vs small scale. Van der Bliek, *et al*, (2014) describe irrigation in sub-Saharan Africa as pluralistic as it ranges from smallholder farmer-managed irrigation systems (that produce high value crops) up to large scale public (or even private) irrigation systems producing staple grain crops and cash crops for the local and export market. They further state that falling between these two are medium scale irrigation systems that generally are community operated and managed producing basic staple crops, vegetables and fruits for both the domestic and regional markets. The idea in this discussion is not to *a priori* select one scale over the other but to highlight the advantages and applicability of each for given circumstances or situations and the prospects for adoption adaptation for improving rural livelihoods in Chinyanja Triangle.

The third aspect to be covered in this section is highlighting whether emphasis should be on the AWM technology as artefacts (hardware) versus the soft issues related to that hardware (management, institutions and so on). It will be argued that both are critical to the success of any AWM intervention. However, slightly more emphasis effort will be put towards identifying the AWM intervention as technologies and then juxtaposing any key management requirements for the success of such interventions, including cross-cutting issues such as gender, land tenure, climate change, policy and institutions.

It must be stated that there is a substantial amount of literature on the array of AWM interventions available that are or could be applicable to Chinyanja Triangle. The question that arises then is '*how can one identify the most appropriate AWM intervention for Chinyanja Triangle or specific communities therein*'? Whereas in the past this would have been an onerous task, today there are tools and models available that could be applied to assist in identifying conditions existing on the ground that would enhance the chances of adoption or uptake of a given intervention or technology under those conditions. One such tool is the Targeting AGwater Management Interventions (TAGMI) model or tool recently developed by Stockholm Environment Institute (SEI) under the Challenge Programme on Water for Food (CPWF) Phase II research project. See Box 1 for a brief on TAGMI. It is indeed proposed or recommended in the end that such a model be applied for specific conditions or cases in the Chinyanja Triangle to identify potentially adoptable AWM interventions in specific areas.

Box 1: Brief on the the TAGMI model (abridged from TAGMI fact sheet http://www.seimapping.org/tagmi/documentation.php#project-outputs)

> Targeting AGwater Management Interventions (TAGMI) is a decision support tool that facilitates targeting and scaling-out of three different Agricultural Water Management (AWM) technologies in the Limpopo and the Volta River Basins. TAGMI assesses the *Likelihood of Success*. This online tool displays the output of a Bayesian network model that assesses the influence of social and bio-physical factors on the likelihood of success of implementing different AWM technologies. TAGMI displays spatially explicit model results at the district scale, based on available data, to determine which districts may be better suited than others for a particular technological intervention. TAGMI helps to answer the question: *will an intervention successfully applied in one location have a reasonable chance of success at other locations?* The answer, provided with a measurable degree of certainty, suggests a way forward for scaling-out AWM interventions. It is intended for non-technological expert users who want to know which parts of the river basins have conditions suitable for successful implementation of a planned AWM intervention.

For projects of a water harvesting nature, Lasage and Verburg (2015) propose a decision support framework (DSF) to aid organisations and individuals who are involved in the implementation of water harvesting projects to select appropriate and informed techniques. The framework is premised on the user perspective (rather than the technical or physical perspectives), i.e., purpose of water harvesting. Details of this DSF can be found in the above reference.

With the above proviso, the next section briefly discusses all possible options on irrigation based SAI for Chinyanja Triangle.

3.1 Brief on all Possible Irrigation-based Agricultural Water Management Interventions (AWMI) for the Chinyanja Triangle

There are several ways of categorising AWM interventions (see Subsection 1.2) and these could be based on irrigation technology, scale of operation, nature of water lifting, management type, and so on. In this report the categorisation will be based on both scale of intervention and water lifting approaches. The choice of using scale is quite obvious because we are looking mainly at smallholder farmers. Water lifting technology is important because historically it has always been argued that this can make or break the success of irrigation interventions, whether schemes are gravity irrigated or have pumped systems, with the latter considered problematic unless if farmers engage in profitable agriculture, e.g., horticulture production for the market. In a recent paper, Dessallegn and Merrey (2014) have discussed the important role pump water lifting technologies have revolutionised irrigation in Asia and are also slowly, but significantly, making inroads in sub-Saharan Africa. Namara, *et al*., (2014) on research work done in Ghana, flag the point that pump technology tends to be restricted to well-off farmers and wider dissemination is curtailed by poorly developed supply chains, lack of access to finance and high operational and maintenance costs. Thus it makes sense to consider water lifting technologies in the categorisation of irrigation-based AWMI.

The summary comparisons of the AWMI are presented in Appendix A as Table A1. Table A1 provides the key advantages and disadvantages, role of the smallholder farmer and prospects of applicability to the Chinyanja Triangle. Due to the large number of possible interventions, the presentation in this report can only cover so much without getting too unwieldy. The presentation of each AWMI will take the format of briefly explaining the technology, outlining its key advantages and applicability to the Chinyanja Triangle and the role of the smallholder farmer. The smallholder farmer will be considered from all angles, e.g., from food and cash crop production as well as prospects of getting employment or generating employment from the said intervention.

3.1.1 Large scale commercial irrigation (LSCI)

Large scale commercial irrigation (LSCI) is irrigation development that is on a large scale, in terms of area and scale of operation, and tends to be centrally managed as a private commercial undertaking. Large scale commercial irrigation is sometimes considered as alien and capitalistic when taken in the context of small scale rural development projects, and is often laced with unkind terms such as 'exploitative'. In reality one need not be blinded to the fact that LSCI has successfully been used in a number of countries in the region for both rural development and general national economic development. Examples that come to mind include the commercial irrigated sugarcane estate found in South Africa, Zimbabwe, Swaziland and Mozambique. These LSCI development projects have contributed significantly to rural development in these countries with the consequent benefits of uplifting rural livelihoods, as well as contributing to national economic development and food security.

LSCI has found traction with national governments in recent years through the need to be self-sufficient in food, given the recent rise and fluctuations in food prices (Merrey and Sally, 2008). Government driven LSCI has been found to contribute to food security as well as national development and bring about other advantages that include rural infrastructural development (roads, electricity, dams, factories), increase in the value of land (irrigated land is more valuable than non-irrigated land), increased revenue to government (through levies and taxes), and offered import substitution opportunities (food produced locally and not having to be imported). Of course such development also has disadvantages, but one hopes with properly planned and developed LSCI, the advantages would outweigh the disadvantages.

An interesting and sometimes divisive element of LSCI is the advent of so-called 'land grabs', i.e., international land agreements by foreign governments or companies. Typically, foreign governments lease huge tracts of land in less developed countries for own food production. In sub-Saharan Africa, such developments have taken place in countries such Ethiopia, and Sudan by China. These types of interventions, invariably, have an irrigation component. The benefits that rural communities as well as national governments derive from such deals depend to a large extent on the conditions of the agreements that would have been negotiated among the concerned parties (Cotula, 2011; Woodhouse, 2012). In poorly negotiated deals, as is the case most of the time, such LSCI interventions have indeed been exploitative and disenfranchising to the rural poor through loss of land and water (Cotula, 2011; GRAIN, 2012;) and inadvertently turning them into indentured slaves or contract workers in these large scale irrigation projects.

Prospects for SAI through large scale commercial irrigation interventions: In summary, LSCI interventions have deliberately been included in this discussion to ensure that, as assessments of irrigation led interventions in the Chinyanja Triangle are considered, these considerations are not blinkered to the exclusion of possibilities offered by LSCI. The investment costs associated with LSCI are, admittedly, high and probably out the scope of the CRP project but this does not mean such interventions could not be studied and recommendations made to those with the mandate, resources and will for such projects. As has often been said, sometimes one has to 'think big' to get out of the poverty trap that most rural communities in sub-Saharan Africa find themselves in. Examples exist from places such as Swaziland (Mutiro, 2015) were government and donors are funding fairly large scale irrigation development in which smallholder farmers are shareholders in a sugar cane irrigation company.

3.1.2 Smallholder communal irrigation – river diversions, storage works and pumped water supply

The bulk of the so called smallholder (small-scale) irrigation schemes (SIS) in the world falls into this category. It is characterised by farmers having to share water resources and often as well irrigation infrastructure, and need to collaborate in order for them to receive the water to irrigate their crops (Van Averbeke, *et al*, 2008). Typical landholding size ranges from 0.1 ha through 2.5 ha up to about 5 ha, although project with up to 10 ha can also be found. Depending on location, various water lifting options exist and these include; river diversions using canals or with low lift, storage works with canal diversions or storage with low lift, and also pumped water using electricity or engines of one form or the other. The type of water lifting has a significant impact on the operation costs of SIS. Those operating on river diversions or low lift tend to have low operational costs, compared to those operating on pumped water, given the rising cost of electricity and fuel as well as the required running cost to maintain engines for water pumping. More often than not, electricity or fuel are not readily available in remote areas were such SIS tend to be located.

Smallholder communal irrigation comes in various forms, ranging on one end from that which is initiated, planned, designed and implemented with almost 100% government input and government also having a hand in the management of such schemes. On the other extreme one can find smallholder irrigation schemes that are initiated, developed and managed by the communities with very limited central government input. Both types of SIS offer advantages and disadvantages. The former type tends to have; initially better planned and laid out infrastructure, formal by-laws guiding scheme management and operations, irrigation runs in an orderly manner, and the irrigators reap the benefits of government assistance. Some of the disadvantages or problems associated with this type of irrigation could include; neglect of scheme infrastructure because it belongs to government, reliance on government for scheme maintenance, inefficient operations as tends to be inherent in government run schemes, conflicts among irrigators, and structured operations that do not relate or respond to realities on the ground, e.g., fixed crop choices and crop rotations even if these are not financial viable.

On the other end for farmer initiated and managed irrigation schemes, these have received positive reviews when assessed (Giordano, *et al*., 2012) and have almost become the recommended model of development by some donors such as IFAD (InnoWat, 2014). These types of smallholder irrigation interventions have been found; to operate fairly efficiently, to be financially viable through growing high value crops that give better returns, to have low operational overheads as the irrigation technology is matched to the farmer and scale of operation, and to be generally sustainable in the long term as farmers are self-driven and want their projects to succeed. Problems associated with such irrigation development may include; poorly laid infrastructure due to low resource input during development, conflicts among irrigators if there is no group cohesion, risk of abandonment if other livelihood opportunities arise (e.g., artisanal mining), and high exposure to the vagaries of both the economy (e.g., lack of markets and drop in produce prices) and the weather (e.g., droughts and floods) as the level of operations and system design may lack adequate buffering.

If one looks at things from a global perspective, there is general discontent with SIS interventions simply because it is argued that in many instances these have failed to live up to the expectations in terms of benefits, and the development has also tended to run over budgets in most cases, leading to the so-called 'developed half the area at double the budget' problem. Furthermore, in terms of infrastructure operation and maintenance, SIS has tended to suffer from the 'develop, abandon and rehabilitate' syndrome (Vernot, *et al*., 2012) whereby development takes place, then the project is abandoned to the smallholder irrigators until it deteriorates before government or donors come and rehabilitate it. The above negative sentiments are quite understandable given the competition for development resources, the need to realise development benefits almost immediately, and the unfair or incomplete performance assessment of SIS that fails to properly capture and quantify some of the social and downstream benefits associated with these schemes.

Prospects for SAI through smallholder communal irrigation: Smallholder communal irrigation would be applicable in the Chinyanja Triangle simply because this type irrigation development model is familiar to most governments and donors involved with rural development. It allows governments and politicians to have something tangible for the electorate and is also easy to justify to international donors as part of rural upliftment programmes on poverty alleviation, food security, and rural development. At the project feasibility stage, it is quite a straight forward issue to tweak the relevant variables (e.g., crop yields, produce prices, number of beneficiaries, etc) for the project to end up with a positive economic internal rate of return (EIRR) and therefore secure funding. The bulk of donor funding for smallholder irrigation development has gone into such projects.

The biggest challenge faced by smallholder irrigation is to ensure operational sustainability in the long term, especially for those developed by government. Time and again such irrigation development projects have failed to live up to expectations in terms of performance and intended benefits. They continually become depended on government to bail them out in terms of operation and maintenance. Research efforts should therefore focus on finding a development approach and management model that ensures long term sustainability.

3.1.3 Smallholder individual irrigation

As the name suggests, this type of irrigation is based on individuals developing their own stand-alone irrigation. In some cases these are termed smallholder commercial irrigation as farmers may have freehold title to the land and thus are able to secure loans for irrigation development using and other resources as collateral. The size of the units could vary from as little as 1 ha to as much as 20 ha. These are not to be confused with the above category of communal but individually developed schemes. Smallholder individual irrigation tends to be complete and self-contained, i.e., the farmer may have an individual pumping unit, own irrigation system hardware that can be operated independently without necessarily having to deal or liaise with anyone else. This category of irrigation intervention has tended to be individualistic, driven by individual motivation to succeed and therefore the crops grown and the marketing arrangements are targeted at being financial viable. Success stories are abound of how individual smallholder has uplifted families to states of food self-sufficiency (Postel, 2013).

In some cases, like in Zimbabwe and South Africa, such irrigation development is closely tied in to the large scale commercial irrigation systems and is termed 'out grower' schemes. In the out grower scheme model, the famer may have access to water (and possible other inputs) through the large scale scheme. Be that as it may, a key requirement of such schemes is that they need to be financially viable as they do not get any direct subsidies or bailouts from central government.

The key advantage of such irrigation interventions is that they allow motivated individuals to make progress without being encumbered by other, probably poorly motivated, farmers. It allows individuals to focus on financially viable irrigation without having to conform to group requirements, e.g., block cropping and block irrigation. Disadvantages of such interventions may include; low economies of scale because of small units unless if they grow very high value crops, and conflicts may arise with neighbours on access to water depending on the scale of operation and the type permit held by the farmer.

<u>Prospects of SAI through smallholder individual irrigation</u>: Under this type of intervention the irrigators can play the role of being farmers and also have the potential to employ other people, depending on the scale of operation. The potential for poverty alleviation can be considered as good to high and that of individual food security and economic development are moderate to good.

3.1.4 Smallholder communal sprinkler irrigation

This type of intervention is basically the same as smallholder communal irrigation with river diversion except that in this case the systems are pressurised and irrigate using sprinklers – quick-coupling hand move systems, dragline systems or even centre pivot. These systems are categorised separately because of their peculiarities in energy requirements and hardware management (operation and maintenance). Such systems could be developed with the assistance of government or by individual communities or communities with the help of NGOs and other charitable organisations. Sprinkler systems allow for better water control, are much adaptable to water application to suit specific soils, and are relatively efficient compared to flood or surface irrigation methods.

Sprinkler irrigation lends itself to either group or individual irrigation. For group irrigation one would have a sprinkler irrigation systems irrigating several plots or fields for farmers in a given irrigation scheme. Systems like quick coupling hand move sprinkler are quite adaptable to such irrigation arrangements. Of late, centre pivots have also been advocated for smallholder irrigation by groups of farmers in places like South Africa and Swaziland were the technology has proved suitable for small scale growers in organised associations due to water scarcity (Msibi, *et al*., 2014). In this case, farmers' plots or fields will be under the centre pivot spans and are irrigated as the machine moves around (Mutiro, 2015). Such irrigation almost requires farmers to grow the same crops at the same time so that the irrigation suits all farmers' crops. In reality this is not the case as farmers tend to grow different crops of different ages and different irrigation water requirements. Within reasonable limits, this does not cause problems except in extreme cases when crops that may be ready for harvesting, e.g., cotton or wheat may be damaged if irrigated at this stage when irrigation continues to meet the irrigation requirements of farmers with late crops. Dragline irrigation systems lend themselves to individual farmer control in that a farmer can have one or two irrigations lines dedicated to their plots and can irrigate as and when they so wish. The only requirement is that the system must be designed to cater for on-demand irrigation and this tends to make systems high capacity (power requirements and system flow rate) thus making the initial investment cost somewhat relatively high. Despite this, it has also been found that individual farmers also use their individual units to irrigate different crops at the same time.

Disadvantages associated with sprinkler irrigation include; hardware maintenance issues such as serving and replacing worn out components. Sprinkler equipment useful life is rated at 10 to 15 years compared to canals in flood irrigation that may have a useful life of 40 to 60 years, meaning sprinkler systems have to replaced or rehabilitated more often than flood systems. This tends to be an ongoing concern with sprinkler systems. In cases were equipment is shared, i.e., sprinkler units used for irrigation shared amongst farmers, conflicts tend to arise over the control of equipment, especially if irrigation is on a rotational basis whereby one can easily hold on to the equipment when it's supposed to be handed over to the next irrigator. Another problem associated with sprinkler irrigation equipment is that of hardware theft, especially aluminium pipes and brass sprinkler heads. This brings in the added cost of securing the equipment, e.g., having to cart it home at the end of irrigation every day. Due to pressurisation requirements of sprinkler system it means the running (operating) costs tend to be high (because of electricity or fuel charges). The cost of pumping water can impact on the viability of the related irrigation enterprises. Proper operation and management of sprinkler require that the equipment be depreciated and resources put aside for the eventual replacement of the system. This aspect is lost to many irrigators, especially smallholder farmers, consequently if a component breaks down or fails, there will be no resources available for its repair or replacement.

<u>Prospects for SAI with smallholder communal sprinkler irrigation</u>: With regard to the applicability of smallholder communal sprinkler irrigation to the Chinyanja Triangle, this is a distinct possibility. Sprinkler irrigation would be appropriate for those farmers growing crops of reasonably high value to enable them to be able to pay for the pumping costs. For farmers who have traditionally used flood irrigation systems, sprinkler irrigation is normally considered an advanced technology and farmers tend to want to be seen to be advancing with time. If water is a concern, for example in arid or semi-arid regions, the water savings from sprinkler irrigation can be substantial (75% efficiency compared to 45% for flood irrigation) thus allowing more farmers access to the limited water, or more land can be irrigated (provided one does not get the Jevon's paradox – water savings due to efficient irrigation result in more water being consumed through increased irrigated areas!) with the same amount of water, hopefully leading to benefits for more and getting more output per unit of water consumed.

The prospects for poverty alleviation as well as improved food security can be assumed to be good. It is expected that farmers will grow both high value crops (e.g., tomatoes, potatoes and various vegetables) and food crops (e.g., maize, wheat) under sprinkler irrigation, provided they are linked to markets

Possible research issues required with this intervention would include management of the system to ensure that they remain operational at all times, and that the sprinkler systems are depreciated appropriately and money put aside for replacement at the end of the equipment useful life.

3.1.5 Smallholder communal drip irrigation

Drip irrigation is characterised by systems that operate at low pressures and apply low volumes if water frequently to crops. Drip irrigation offers several advantages that include; high application efficiencies (upward of 90%) meaning a little water goes a long way, better use of water by crops as it is applied frequently, better use of fertilisers by crops because of the frequent wetting, water application is not affected by wind, systems can be automated so that they operate for longer and possibly continuously, and the systems have low labour requirements which would suit families or communities that are labour constrained. Some of the disadvantages of drip irrigation include; relatively high initial capital development costs per unit area, impediment to field operations because of permanently installed equipment, drip cannot be used on low value crops such as maize or crops that are broadcast (drilled) like wheat, and drip does not do well on highly pervious soils, such as sands which are found in a lot of the smallholder farming areas in the region.

Drip irrigation has not found mainstream adoption or application by smallholder farmers in a communal setting. This is probably due to the high costs when compared to flood or sprinkler irrigation system, as well as the fact that it not necessarily suited to the irrigation of food crops like maize and wheat. Also without proper management, drip irrigation is highly prone to clogging problems rendering it literally useless and inoperable. Furthermore drip irrigation by design means the equipment is permanently in the field and this impedes field operations, such as land preparation or secondary tillage, unless if the equipment is removed and then re-laid afterwards for irrigation. Added to the above is the fact that drip irrigation is predominantly plastic piping that can easily be damaged (during field operations or by wild animals) meaning that maintenance and repair costs are likely to be substantial. In group irrigation, it is quite possible that there might be conflicts over access to and use of the equipment. A common problem is that drip systems are designed to irrigate blocks in rotation, but in shared systems irrigators may want to irrigate as and when they please, thus coming into conflicts with those who would genuinely having the right to irrigate at that moment in the irrigation cycle.

<u>Prospects of SAI using smallholder communal drip irrigation</u>: Drip would be applicable to the Chinyanja Triangle in cases where farmers were irrigating high value crops for the markets. This is critical given the high costs associated with drip development and maintenance. Possible crop choices would include various seasonal horticultural crops such as tomatoes, onions, green peppers, cabbages and so on. Alternatively farmers could grow under drip irrigation permanent crops such as high value fruit trees. Either way drip irrigation would be helpful in offering efficient irrigation using limited water amounts.

The prospects for economic development can be considered low under communal standard drip irrigation because of the high initial capital development costs and the high managerial capacity required.

Issues requiring further research would include; crop choices for farmers in Chinyanja Triangle vis-à-vis market opportunities available for such crops so that farmers get the expected income benefits, operation and management approaches for the infrastructure if it is shared so that conflicts are minimised, economic management models to ensure that the drip equipment is correctly depreciated and resources put aside for its eventual replacement, and how to best train farmers for them to appreciate the need to properly manage the drip equipment.

3.1.6 Drum and bucket drip kit irrigation

As the name suggest this type of irrigation intervention comprises small drip irrigation units made up of a drum or a bucket connected to 2 or more driplines commanding net irrigable areas ranging from a few square meters up to maybe 5 ha (Daka, 2006). The development costs also range from a few tens of dollars up to US$300 depending on the set-up (Daka, 2006). The drum and bucket drip kits are good and applicable for backyard or home nutrition gardens producing vegetables for own family consumption.

Drum and bucket drip kits were extensively promoted by the UN Food and Agricultural Organisation (FAO) under the Special Programme on Food Security (SPFS) in the 1990s in the many countries in sub-Saharan Africa. In most cases such kits were promoted in conjunction with treadle pumps for water lifting (Kay and Brabben 2000). The approach to the promotion of these kits attempted to be inclusive and also aimed at having most of the kit components manufactured locally in the various countries. There was some success in this with many local small scale industries being able to manufacture the treadle pumps, e.g., ApproTech in Kenya. However, the overall results for this programme were somewhat mixed with reasonable uptake in countries such as Malawi, Kenya and Ghana and limited adoption in places like Zimbabwe (Rohrbach, *et al*., 2006) and South Africa. On a positive note, in Malawi treadle pump irrigation increased crop production by 5 to 54% compare to can irrigation, and also increased gross and net incomes by more than 12% indicating that farmers using treadle pumps realised higher incomes across all crop enterprises (Kadyampakeni, *et al*., 2014). It would seem the key to adoption was access to fairly shallow water sources since the treadle pump cannot pump water from anything more than about 6 m deep since it is manually pedalled. In some cases it was found that the farmers had started using the drums and bucket of the drip kits for purposes other than irrigation.

Advantages inherent in the drum and bucket drip kits are the compact size and manageability by individual farmers or families. The scale of operation is fairly small. The disadvantages are that such systems cannot lead to self-sufficiency in overall food needs and the scope for commercial crop production is limited.

Prospects for SAI using drum and bucket drip kits: Applicability of drum and bucket drip kits to Chinyanja Triangle can be considered good for backyard gardens at individual homesteads for vegetable production, provided they are linked to reliable water lifting or rooftop water harvesting into storage tanks. Prospects for nutrition improvement can be quite good but not much in terms of food security because of the limited areal production potential. There is a limit to how much can be produced under these drum and bucket drip kits.

Merrey and Langan (2014) make some strong recommendations regarding garden or bucket kits in Africa, i.e., implementation and research should avoid single dimensional approaches, researchers should avoid making assumptions about interest in and demand for certain technologies (e.g., bucket kits) for home gardens but should aim to understand the circumstances through participatory diagnostic appraisal of actual practices using the Participatory Rapid Diagnostic and Action (PRDA) Planning for Irrigated Agricultural Systems. They further recommend action research based on three objectives; (i) testing the performance and acceptability of some of the bucket/garden drip kit technology, (ii) testing implementation strategies for these technologies and crop production choices, and (iii) adapting available training modules and curricula to specific conditions on the ground. The research that will take place in the Chinyanja Traingle should take heed of the above suggestions.

3.1.7 Moistube irrigation

Moistube irrigation (MTI) is a new type of irrigation recently introduced from China (Irrigation, 2011) into South Africa and basically still being evaluated by the relevant government departments. It supposedly utilizes the membrane technology by means of an artificial semi-permeable membrane to imitate the biological semi-permeable membrane in plant cells. Moistube is composed of a polymeric semipermeable membrane tube and a permeable protective sheath. The tube has approximately 100 000 micropores per square centimetre with a pore diameter range of 10-900 nm. The protective sheath is made from a special type of fabric which has both permeability and endurance and therefore protects the thin-walled tubes. When water fills the Moistube, it will flow or permeate through the membrane by the micro pores and infiltrate into the soil. Due to the membrane's permeability, the system does not require irrigation emitters, drippers, an emission device or any other water feeders (Irrigation 2011).

The purported advantages of Moistube irrigation include; delivering water and fertilizer directly to the crop root zone via subsurface irrigation technology, providing adequate water to the plant roots at the same rate as uptake of water by the plant, and does not suffer from emitter clogging found in ordinary drip irrigation (Irrigation, 2011).

Prospects of SAI using Moistube irrigation: This type of irrigation intervention has the same potential as drip irrigation but unfortunately not much is known about this technology in terms of operational limits, area that can be commanded per given design, range of crops that can adequately be irrigated, irrigation water dynamics in various soils, and durability of the membrane technology under tropical conditions. What can be said at the moment is that it has some potential for the smallholder farmers in the Chinyanja Triangle for small-scale individual food security and nutrition plots using limited amounts of water, but prospects for applicability are low since in unknown technology.

Required research for this technology would be to investigate all the unknowns regarding this technology, i.e., durability of the technology under sub-Saharan Africa conditions, adoptability and adaptability of the technology to local conditions, operational limits of the technology, range of crops that could be irrigated with such a technology, and the applicable installation and operational costs.

3.1.8 Dambo irrigation farming

Dambo irrigation farming has been around for a very long time and is considered an indigenous practice. Dambo farming is comprised of vlei cultivation that takes advantage of shallow water tables whose upward moisture seepage through capillary rise is exploited for crop production with no or limited water control. Dambo farming allows the late production of crops to the normal rain season, as well as early cropping at the end of winter season. A wide range of crops can be grown under dambo farming and these include; green vegetables, tomatoes, sugar cane, maize and even rice. Field crops like maize tend to be grown on raised beds to allow for drainage of the root zone. Dambo farming is often further enhanced by the digging of shallow wells (1.5 m to 3 m deep) to allow for supplementary irrigation if needed. In Zambia it is estimated that probably 3.6 million ha are considered dambos and 100 000 ha of these are cultivated during the rainy season (Daka, 2006).

Dambo farming offers several advantages that include; increased cropping intensities, increased yield, late or early crop production, low operational costs and increased farm incomes. Dambo farming however requires the maintenance of a delicate balance between exploitation of the dambo resource by users and the dambo physical environment, especially recharge rates. Typical problems include the risk of over abstraction of water (from too many users and unsustainable abstraction) leading to the lowering of the water table. Once this balance is upset, dambos can dry out with the consequent loss of farming opportunities.

Prospects of SAI using dambo irrigation farming: Dambo farming offers low cost opportunities for intensifying agricultural production. It's a tried and tested form of production that is indigenous and can easily be improved with limited external inputs. Since dambo farming is already practiced in the Chinyanja Triangle, it should be promoted further, albeit, in a sustainable manner.

Research should look at how to equitably access and use dambos by local populations using the local structures, water balance studies for dambos vis-à-vis potential sustainable usage, and how to effectively link to markets.

3.2 Soil and Water Conservation and Conservation Agriculture Interventions

In the continuum of green to blue water, the bulk of the sub-Saharan crop production is from green water, i.e., rainfed agriculture (Rockstrom, *et al*., 2010; Vidal, *et al*., nd). It therefore makes sense that rainfed agricultural interventions be considered whenever one is discussing food security and poverty alleviation strategies for rural populations whose main economic activities are agro-based (Rockstrom, *et al*., 2010). Although the focus of this write-up is on irrigation based interventions, it will be worthwhile to cover aspects of soil and water conservation (SWC) practices that help in managing water resources for crop production. The main aim of any SWC practice is to make the best use of rainwater, preferably were it falls, i.e., infield rainwater harvesting (IRWH). In cases where water is harvested from elsewhere, for example runoff water from the road side, then this is termed ex-field rainwater harvesting (ERWH). Rainwater harvesting (RWH) is a whole subject on its own, same as irrigation, with many technologies or practices as subsets.

Conservation agriculture (CA), on the other hand, is simply defined as practices that aims at minimal soil disturbance coupled with permanent soil cover combined with reasonable crop rotations. Basically CA aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. The three tenets of CA are minimum soil disturbance, mulching and the practise of crop rotations. CA is considered a complex technology that involves not only a change in many of the farmer's cultural practices, but also a change in mind-set to overcome the use of the conventional plough. CA is knowledge-intensive, and success with the system may depend more on what the farmer does than the level of inputs applied. Although widely touted as a win-win situation, the reality on the ground is a somewhat different with regard to the adoption of CA practices. A review undertaken by Andersson and D'souza (2013) revealed that the challenges faced by smallholder farmers, with respect to the adoption of CA practices, were related more to the challenges encountered with the CA practices than the socio-economic state of the farmers. Similarly, Giller *et al*., (2009) highlighted reservations with regard to the applicability of CA to smallholder farmers in sub-Saharan Africa.

SWC and CA go hand in hand and typical SWC practices are part and parcel of CA. Examples of these include; *fanja juu* terraces, micro-basins, stone bunds, *zai* pits, tied ridges, contour farming, mulching and so on. The reader is referred to the report by Mati (2007) where the details of these and many more practices are given. Suffice to say at this point are brief discussions of each in the next sections so as to allow a proper tie in to irrigation related interventions in Chinyanja Triangle as a holistic approach to dealing with rural development issues in that area.

3.2.1 Micro-basins

Micro-basins aim to retain water *in situ* or to slow down the runoff water velocity. These structures are used to rehabilitate degraded land by water erosion and increased yields have been reported for crops planted on these basins (Ngigi, 2003). Micro-basins are constructed along the retention ditches for tree planting, and they are roughly 1.0 m long and less than 50 cm deep (Previati *et al.,* 2009). The basins are dug during the dry season, to allow planting at the onset of the rainy season and the precise application of fertilizer and manure (Thiefelder *et al.,* 2012).

3.2.2 Zai pits

The aim of the *zai* pits is to increase crop production. The pits are dug in alternate patterns that are more or less a meter apart, with basins that are 30–50 cm wide and with a depth of 10–20 cm (Renner and Frasier, 1995). In the small *zai* pit, organic matter and manure are added to the cultivated area, to improve the soil structure (Renner and Frasier, 1995). *Zai* pits can fit about 10–15 seeds of sorghum or millet and are usually dug during the dry season. The sowing is done at the beginning of the rainy season or during the dry season (Sedibe, 2005).

3.2.3 Fanya juu terraces

The practical aim of the *fanya juu* terrace is to improve plant growth, by minimising water and soil loss. *Fanya juu* terraces are constructed with an embankment that is put in an upslope position and are usually constructed along the contour to capture rainfall, especially in semi-arid regions, and come in various dimensions averaging 0.6m deep and 0.6 m wide and a bund measuring 0.4 m high (FAO, 1993). The construction and maintenance of the fanya juu is labour- intensive, for example, to construct the *fanya juu* terracing on a 15% slope by hand would take 90 man-days per hectare (WOCAT, 2007).

3.2.4 Stone bunds

Stone bunds are stones installed along contour lines in the field. The sediment that accumulates behind the semi-permeable stones results in the development of progressive terraces (Vancampenhout, *et al*., 2006). The benefits of stone bunds include increased soil water status and crop yields (Zougmore, *et al*., 2000). The performance of stone bunds has been found to be optimum under water-limiting conditions, e.g,, arid and semi-arid areas. The stone bunds also serve as a barrier to water- induced soil erosion (Vancampenhout, *et al.,* 2006).

3.2.5 Tied ridges

Tied ridging aims to reduce surface runoff and increase soil water storage in the field. Tied ridging has been found to be effective in increasing soil water storage and reducing surface runoff from fields resulting in increased crop yield in countries like Zimbabwe, India and the USA (*Brhane, et al*., 2006).

Tied ridging involves creating ridges that are 0.2 m to 0.3 m high with a spacing of 0.75 m wide. The ties can be prepared either before, during or after planting (Brhane, *et al.,* 2005).

3.2.6 Contour farming

Contour (across-slope) cultivation refers to farming along the lines of equal contour (FAO, 1998). The establishment of any crop in contour farming will first require systematic tillage to be applied on the land, meaning also that soil preparation and terracing should be established along the lines of the contours.

3.2.7 Minimal soil disturbance (for CA)

Minimum soil disturbance for conservation agriculture is epitomised by conservation tillage which is a set of practices that leave crop residues on the surface, which increases water infiltration and reduces erosion. Conservation tillage is a collective umbrella term commonly given to no-tillage, direct-drilling, minimum-tillage and ridge-tillage, to denote that the specific practice has a conservation goal of some nature (Baker, *et al*., 2002).

3.2.8 Mulching (for CA)

Mulching is the use of crop residues to cover the soil. Soil mulching reduces wind and water erosion (Hobbs, *et al*., 2008). Soil mulching has a number of benefits such, as reducing evaporation (thus enhancing soil moisture conservation), moderating the maximum temperatures in the soil surface layers, improving soil water infiltration, increasing soil porosity and increasing soil aggregate stability (from increased soil organic matter) (Grabowski, 2008; Giller, *et al*., 2009). Crop residues can be sourced through various means, varying from cover crops (e.g legumes) grown and cut to specifically provide mulch, or from a previous crop left after harvest.

3.2.9 Crop rotations (for CA)

Crop rotation is when different crops are grown in sequence on a piece of land thus making full use of physical & chemical interactions between different crop species to achieve multiple purposes such as reducing soil erosion, breaking pest cycles, improving soil moisture conservation, de-compacting the soil, cycling and generation of nutrients, and minimising the progressive development of unfavourable conditions in the field. Crop rotations differ as a function of location, climate, farming systems, soils, erosion problems, and erosion severity.

Prospects of SAI using soil and water conservations and conservation agricultural interventions: SWC and CA offer almost limitless opportunities for SAI in the Chinyanja Triangle because of their wide applicable and adoptability to such set-ups. In classical fashion, Rockstrom and Falkenmark (2015) recommend an increase in water harvesting in Africa in order to meet the food needs of the continent through storing rainwater and retaining soil moisture to bridge dry spells. Most of the SWC and CA practices are simple, require minimal inputs, do not require extensive knowledge base, are applicable across farming spatial scales (from small scale to large scale), and offer observable and tangible benefits. Many cases exists where SWC practices have resulted in improved water management leading to improved crop performance resulting in improved food security and improved livelihoods for rural populations (Daka, 2006; Mati, 2007; Merrey and Sally, 2008). The benefits of SWC and CA are undeniable. Because of this, many international organisations such as FAO and IFAD as well as national governments and various NGOs and charitable organisations have invested in the promotion of these technologies and practices. As an example, the investment in agricultural water by IFAD and co-financier in the period 1990 to 1994 was an estimated US$118 million per year and this increased to US$176 million per year in the period 2000 to 2004 (InnoWat, 2014). For example in sub-Sahara Africa, CA has been promoted for over 30 years.

As part of the Chinyanja Triangle development plans, SWC and CA practices must be considered in tandem with or complimenting irrigation related interventions. Since farmers are considered guardians of the world's natural resources, research that empowers them to improve water productivity and double harvested rainwater is required (Rijsberman, *et al*., 2015).

Further research is required to understand why the sustainable adoption of SWC and CA is limited in the long run. Despite the investments made by governments, NGO's and research institutions, the adaptation and adoption of these practices is still low, especially among smallholder farmers (Perret and Stevens, 2003; Giller, *et al*., 2009). In southern Africa, the adoption of RWH has been low, even though the benefits of it have been apparent (Mutekwa and Kusangaya, 2006). Interestingly in South Africa, CA has been widely adopted by large-scale commercial farmers (mainly for economic and environmental reasons), yet for smallholder farmers adoption is still low (Johansens, et al., 2012). A number of econometric modelling studies have been undertaken that have isolated and identified key factors militating against adoption of SWC and CA practices, but it has not been easy to convert this knowledge or information into practical application to increase uptake of the technologies.

3.2.10 Other Bright Spots

Years back, IWMI worked on the concept of 'Bright Spots' in African agriculture based on successes and successful development in communities, with the term coming from Haggblade (2005). For want of a definition Bright Spots can be defined as individuals, small communities and households that have adopted innovative practices and strategies to reverse natural resource degradation in a sustainable manner whilst maintaining or enhancing food security. As an explanation of the concept, Bright Spots are community successes characterized by agricultural communities and households that are doing much better than neighbouring ones despite environmental, social or demographic pressures (Penning de Vries, 2005). Three types of Bright Spots are identified, that is, spontaneous, technical, and community-based successes and these would each have different set of drivers. Four typical types of drivers of Bright Spots, according to Noble, *et al*., (2005), are; spontaneous (cases where individuals drive the process), social (situations where informal organizations champion the process), technological (with either new hardware or information about it) and external (process is driven by facilitators, markets or donors). To enable extended up scaling of Bright Spots the following conditions need to be in place; markets for the products, security, policies, institutions and basic education (Penning de Vries, *et al.,* 2005).

Brights Spots that have been documented in Africa comprise improved land and water management strategies and practices that have had the positive consequence of increasing yield (a weighted average increase of 2.65%) and impact on the environment, at an average investment cost of US$336/ha (Noble *et al*., 2005). These land and water management strategies include; soil and water management practices such as zero tillage, IRWH and ERWH, and community based practices that include smallholder irrigation and watershed management programmes.

Ten key elements were identified as being of key importance to the development of Bright Spots (Noble *et al*., 2005). These are; (i) benefits must be quick and tangible, (ii) there must be a low risk of failure, (iii) market opportunities need to be present and be assured, (iv) individuals or communities must aspire to change, (v) there must be innovation and also new technologies, (vi) champions of change are needed, (vii) there is need for social capital, (viii) participatory approaches that involve communities are needed, (ix) elements of property rights and ownership need to be in place, and (x) supportive policies are required at all levels – local, regional and national.

Prospects of SAI using Bright Spots approaches: The argument for SAI in the Chinyanja Triangle using the bright sports more or less go hand in hand with the discussions above on soil and water conservation practices as well as conservation practices. Given the premise from which Bright Spots are coming from, the Bright Spots approach would find relevance and application in the Chinyanja Triangle – strategies and innovations that are home grown, driven by the local people, yielding benefits at low investment costs with prospects for out scaling and up scaling.

3.3 Critical Issues to Key Sustainable Agricultural Intensification (SAI) Options

Regardless of the proposed irrigation based SAI options for Chinyanja Triangle, some critical and cross-cutting issues need to be analysed or brought to bear on the whole argument so that the interventions will have a chance of success. These issues include; gender related considerations, the socio-institutional set-up when interventions are introduced, access to land by women and vulnerable groups, access to water by all engaged in irrigated agriculture, water-food-energy interactions, transboundary issues in relation to water as well as water governance issues, equity issues, climate change necessitating climate smart agriculture, adaptability of irrigation technologies being promoted based on their robustness, access to markets and prospects for commercialisation, and many others. Each of these factors is a whole discipline of study on its own, so no attempt will be made to discuss any in great detail but to flag what needs attention in the Chinyanja Triangle research and development endeavours for a few of these.

Reflecting on the DFID (1999) Sustainable Livelihoods Approach (SLA) or Framework may perhaps help to put all the factors mentioned above into context. The SLA argues that the analysis of livelihoods or the requirements for rural development can all be embodied in five different capitals or assets, and these are, human assets (skills and knowledge, health) , natural assets (water, land, genetic resources) , financial assets (savings, loans, credit), social assets (organizations, regulations, policies, trust and security, gender equity) and physical assets (infrastructure, equipment). The SLA further argues that if any one of these assets or capital is not available or is inadequate, it hampers or constraints development, practically meaning that efforts should be expended by development practitioners and communities towards making that capital available. By extension this means that development should be targeted at the smallest capital or asset out of the five.

3.3.1 Gender related considerations

Gender is a cross-cutting issue in agriculture and rural development. As already alluded to earlier on, women make up the bulk of farmers in sub-Saharan Africa therefore any agricultural related interventions must, of necessity, take gender into consideration. A substantial body of literature exists on gender considerations in irrigation – from design (Matshalaga, 1999) to role in irrigated farming (van Koppen 2001; van Koppen, 2002) and on to high end irrigation technologies like drip irrigation (Upadhyay, 2005). SAI being proposed must take into account gender considerations such as; what could be the gender based constraints being faced, the role of women in agricultural production, gender linkages to up scaling innovations and practices, access to means of production by women, multiple roles of women and biases towards women access credit facilities. Suffice to say is that all the AWMI based SAI in the Chinyanja Triangle must be looked at and understood within the context of gender. Gender aspects are also included under Sections 3.3.4 and 3.4.5.

3.3.2 Socio-institutional set-up

Technology or hardware tends to be considered as 'a constant' and the variables that determine its success or failure is the socio-institutional set-up in place to manage and provide an environment for its successful adoption. In irrigation development, management arrangements determine, to a large extent, the success or failure of any intervention. Management structures are required to manage the technology so that irrigation can be effected, especially in communal irrigation schemes. Typically this is where you find the creation and existence of management structures such as Water User's Association (WUA) or Irrigation Management Committee (IMC). Such management bodies may or may not be formalised, but generally tend to have powers and authority to run affairs of the irrigation schemes. In recent water reforms that have taken place globally and in the region, efforts have been made to formalise the WUAs or IMCs and give them by-laws that guide their operation (e.g., SANWA ACT 36 of 1998 in South Africa). The WUA may have subcommittees that include; water and maintenance subcommittee, finance and marketing subcommittee and a crop production subcommittee. Common key members would include a chairperson, secretary, treasurer and other committee members. Members of such subcommittees may require going through some training (formal or informal) for them to operate effectively. Were WUAs and IMCs are fully effective, irrigation interventions tend to succeed, relatively, compared to those cases when such structures are not in place.

An important research issue required here is to identify and implement management structures that are suited and relevant to the conditions existing at a particular place. More often than not interventions fail because operational structures that worked elsewhere are transferred or implemented wholesale at new locations without modification or adjustment to suit conditions at the new place. As an example, a smallholder irrigation scheme using canal flood irrigation may have a canal subcommittee whereas one using pumped water lifting will need a pump subcommittee because that is what is relevant in the latter case. Often, it has been said socio-institutional arrangements are the 'Achilles heel' of smallholder irrigation related interventions.

3.3.3 Policies

The policy environment plays a significant role in the success of most rural development programmes as it forms the base upon which interventions can subsist through adequate support and facilitation. Typically the argument is that government should make policies that create an enabling environment. A classic example is how supportive policies enabled the Asian Green Revolution to thrive and ensure food security through breeding of short rice varieties, improved water management and access to markets and price incentives. In the context of the Chinyanja Triangle, the governments of Zambia, Malawi and Mozambique should develop policies at the local and national level that enhances the sustainable adoption of SAI for the upliftment of rural livelihoods in the area. Such policies could include price incentives for excess produce by farmers, development of rural infrastructure to enable farmers to access markets, price subsidies on fertiliser and seed, availing low interest rate loans to farmers, and minimising bureaucratic red tape that hampers rural development.

3.3.4 Access to land by women and vulnerable groups

Regarding access to land, the dominating arguments have been; access to land (as individuals or collectively), right to land (as individual or group), land tenure (formal or informal, statutory or autonomy, permanent or temporary) land tenure security, land governance (relating to transparency and accountability), use of land (for protective or productive irrigation), management of land (intensive or extensive) and scale of operation on the land (smallholder or large scale) (FAO, 2013). It is apparent from the above considerations that land issues are key to agricultural production, food security and rural livelihoods improvement.

One element that has been argued time and again is the positive correlation between women, land and food security (Richardson, 2013). Ownership and control of land by women determines what households produce, generally they grow more and earn more. Furthermore it determines how proceeds from agricultural production are spent or allocated, again, generally when women are in charge of land, a larger proportion of the proceeds are spent on caring for the family (compared to the case of man) and a larger proportion of that goes to food issues (Richardson, 2013; USAID 201; USAID, 2011). Thus giving ownership and control of land to women significantly improves household food security.

From the above it is thus almost imperative that for any irrigated interventions in Chinyanja Triangle to succeed in the objective of agricultural production and food security, women's access to land and land tenure must be secured through legitimising it, for long duration, and women's land rights must be enforceable and be freely exercisable without reference to men. Securing women's land rights contributes to gender equality, improves food security and reduces poverty for the whole family.

3.3.5 Access to water by irrigators, including women and vulnerable groups

For millions of smallholder farmers, fishers and herders, water is one of the most important production assets. Securing access to and control and management of water is key to enhancing livelihoods, especially in Africa (UN Water, 2015). Water is key to any irrigation related interventions because without water (and land) there is no food production. The debate on access to water by smallholder farmers is an old one considering that water varies in space and time and also in quantity and quality. All this implies water must be managed properly. Access to water for primary use is guaranteed in most water legislation in the region. Water for productive purposes is secured through water rights or more appropriately water permits. Such permits allow communities or individuals to access water as a given flow rate or volume of water at a certain time and location. Most smallholders' irrigation water is secured and held through the relevant parent ministry or government department (e.g., Department of Irrigation or Department of Agriculture).

Practically speaking water is always in short supply for most irrigators, leading to conflicts over access to water. Under such circumstances, the vulnerable members of society tend to come worse off leading to a vicious cycle of low food production, food insecurity and poverty. As for the case with access to land, giving water access to women has a positive link to family food security. Thus, women's right to water and security of that right is very important. Research should focus on finding ways of ensuring access to water by women and vulnerable groups and also making sure that they have security of the water right.

3.3.6 Water governance

Water governance issues have received a substantial amount of attention in the recent past, both international and regional. Water governance is indirectly defined as including political, economic, and social processes and institutions through which governments, private sector and civil society make decisions about how best to use, allocate, develop and manage water resources (UNDP, nd). Such a definition of water governance allows us to address issues of equity and efficiency, water administration, formulating rules and responsibilities of various stakeholders (UNDP, nd). Good water governance is required for holistic water resources management, especially in the face of competing demands for the same water.

Since water is a key input in irrigated agriculture, water governance issues at the national, basin, catchment, and field scale need to be researched. The aim of the research should be to generate water governance models that suit the conditions obtaining the Chinyanja Triangle. Consequent to this would be to ensure that access to water, equity of access, efficiency of use and its administration is optimised for the benefit of the rural population of Chinyanja Triangle.

3.3.7 Water-Food-Energy (WFE) nexus

The water-food-energy nexus is a raging debate globally, and it highlights the inextricable link between water, food and energy. In elementary terms, a change in water affects food and energy, a change in food demand affects water energy and a change in energy demand affects water and food. Put in other terms, it refers to the competition for water between food and energy production since water is an input to both food and production. This completion puts pressure on the water resources and the drivers for this are increasing populations, increased urbanisation and growing middle class in m any places whose diet has more meat which requires more water to produce.

Although the large debate on WFE nexus may seem somewhat far removed from Chinyanja Triangle, in actual fact the impacts are much closer to home because of the fact that water is a continuum and flows across boundaries, e.g., the development of a large hydro-electricity project can easily upset access to water by smallholder farmers (and also possibly include loss of agricultural land). Also an increase in water demand at one point can and will affect the amount of water available to smallholder farmers in Chinyanja Triangle and hence their ability to undertake irrigation activities for food security and rural livelihoods improvement.

Research that maybe required in Chinyanja Triangle regarding WFE nexus issues is to model the impact of various scenarios of water withdrawals from the basin(s) and estimate the impact of this on agricultural production and food security. Research would also be required in studying the efficiency of water use in the basin, from field level up to basin level. Results from such research would help to guide developers in the most optimal way to allocate limited water resources for maximum societal benefits.

3.3.8 Climate change necessitating climate smart agriculture (CSA)

As has often been said, 'climate change is for real' (IPCC) and global circulation models (GCMs) simulation results tell us more or less what would happen in various basins in terms of temperature and rainfall regime changes, all impacting on availability of water impacting the ability to practice productive agriculture. There is a substantial body of knowledge on this worldwide, including Southern Africa. One typical model results predict that yields of maize in southern Africa could drop by more than 30% by 2030 (Nosowitz, 2014).

From the above, researchers, development agents and governments are now promoting the adoption and practice of climate smart agriculture (CSA). CSA is loosely defined as adjusting all forms of agriculture (farms, crops, livestock, aquaculture and capture fisheries) to better adapt to a changing climate (ref). Thankfully, there already are CSA toolboxes, guidelines and source books and references housed by the United Nations Food and Agricultural Organisation (www.fao.org/climate-smart-agriculture/en). In sub-Saharan Africa, 'no regret options' for climate change adaptation, that is options that increase the resilience of communities not only to climate change but to any type of shock, have the highest probability of success both in the short and long term (UN Water, 2015).

For Chinyanja Triangle the research that is required is better or localised climate change studies so as to advise on the best CSA practices to develop, promote and purvey to the smallholder farmers of the area.

3.3.9 Adoptability and adaptability of irrigation technologies being promoted

Studies in irrigation technology (hardware) development and adoption have long shown that several factors are critical to the success of their uptake (Cornish, 1998). In as far as the technology characteristics are concerned, some of the following factors have been raised as being key to technology uptake; complexity, divisibility, cost, compatibility, profit, acceptability, trialability and observability. Juxtaposed onto these factors are the socio-economic conditions of the smallholder farmer who is to adopt or adapt the technology. Research has shown that farmer characteristics (e.g., age, education level, access to knowledge, resource endowment, access to land, and so on) (Rogers, 1995) strongly influence the farmers' likelihood to adopt irrigation and soil and water conservation technologies or practices. In a global meta-analysis of the adoption of agricultural and forestry technologies by smallholder farmers, Pattanayak, *et al*., (2003) found that factors which explain technology adoption within an economic framework can be grouped into five categories: preferences, resource endowment, market incentives, biophysical factors and risk and uncertainty. Risk, biophysical and resource endowments categories were found to likely significantly influence adoption behaviour. Others argue that intrinsic factors such as knowledge, perceptions and attitudes (KPA) of the potential adopter towards an innovation play a significant role (Meijer, *et al*., 2014)

In short the adoption of a technology is influenced by the attributes of the innovation characteristics such, as cost, complexity and impact (Damanpour and Schneider, 2008). However due to the fact that the characteristics of SWC techniques such as compatibility, complexity, feasibility and trialability (among other factors) vary with the local socio-economic characteristics of the farmer and environmental benefits, investment in adaptive research is needed to tailor the adoption of these techniques to local conditions (Erenstein et al., 2008). With reference to the Chinyanja Triangle, research is needed to study farmers' characteristics and match these to the technology attributes to identify those that are likely to be adopted or adapted for adoption. Tools such as TAGMI can be used for such research.

3.4 Envisaged Up-scaling Pathways of Key SAI Options and Possible Implementation Routes

So far the report has discussed all AWMI, but the question that maybe asked is out of this listing, which ones could be considered as the key options applicable to the Chinyanja Triangle and how can they be scaled up? One is almost obliged to remain focused on small scale interventions as the bulk of agricultural practices in the area are small scale and smallholder in nature. From the 18 or so agricultural water management interventions discussed a list of six best bet options is derived. The selection of these six interventions is based on; the scale of interventions (mainly small scale), the existence and recommendations of previous studies on possible interventions (namely the work of Mutiro and Lautze (2014) and Daka (2006)), the potential for sustainable uptake based on what is already practiced in the area (as evidenced by literature), the possibility of realising positive results with minimal capital and operational investment (based on literature). It should be stated that the selection of these six does not preclude researching or trying out the other interventions under the Drylands Systems Program. The six best bet options are:

i) small scale irrigation with river diversions,
ii) smallholder irrigation with motorised pumping,
iii) dambo irrigation farming,
iv) drip kits (to include bucket and drum kits) with treadle pumps in areas with shallow water tables,
v) small reservoirs, and
vi) soil and water conservation technologies including conservation practices.

In all these best bet technologies, the production model should comprise both food and cash crop production. Food production crops contribute directly to food and nutrition security, whereas cash crops contribute towards generation of cash reserves that could be used to purchase food (indirectly contributing to food security) or other needs of the families, e.g., buy input supplies for the next cropping season, pay for children's school fees, buy necessary and relevant family assets, and the like. Table A2 in the Appendix provides a comparison of outputs, outcomes and envisaged impacts of the six best bet options fro Chinyanja.

Table 1 gives a qualitative comparison of the agricultural water management interventions (AWMI) proposed for the Chinyanja Triangle in terms of the traditional 'bright spots' criteria for success.

Table 1: Qualitative comparison of the agricultural water management interventions (AWMI) proposed for the Chinyanja Triangle in terms of the traditional 'bright spots' criteria[a] for successes

Note: Some of the criteria elements are better answered as Yes or No, whereas others can be answered as Low, Medium or High (see Comments/Notes for each key element). **Key**: No = means element is not there or not required, Yes = means element is there or is required, Low = key element is low or is not readily realised, Medium = key element is moderate or realised in the medium term, High = means key element is high or readily realised or readily available, Situation dependent = key element is not necessarily dependent on the AWMI intervention but on other factors

'Bright spot' key elements	Agricultural water management intervention (AWMI)						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
Quick and tangible benefits	Medium	Medium	High	High	Medium	Medium	Benefits of smallholder irrigation take time since these are medium to long term type of investments.
Low risk of failure	No	No	Yes	Yes	Yes	Yes	Technologies like drip kits and soil and water conservation have low risk of failure because they are simple.
Presence and assurance of market opportunities	Situation dependent	Situation dependent	Situation dependent	Not applicable	Situation dependent	Situation dependent	Markets and marketing channels are usually situation dependent and cannot be predicted in advance for any technology.
Innovation and new technology	No	No	No	Yes	No	Yes	Strictly speaking smallholder irrigation, dambos and small reservoirs are not new or innovative technologies.
Aspiration to change by	No	No	Yes	Yes	No	Yes	Dambo irrigation, drip kits and soil and water conservation technologies

individuals and community							are normally driven or initiated by individuals or communities.
Need for champions of change	Low	Low	Medium	High	Medium	High	Smallholder irrigation is normally government or donor driven, so the need for champions of change is low.
Need for social capital	High	High	High	Low	Medium	High	For most of the interventions, the farmers need to invest social capital for success, especially in cases where its group or communal activities.
Need for participatory approaches involving communities	High	High	High	Low	High	Medium	Smallholder irrigation, dambos and small reservoir irrigation requires that communities participate so this is a key requirement for their success.
Property rights and ownership elements in place	Low	Low	High	Low	High	High	For dambos, small reservoirs and soil and water conservation the issue of property rights or ownership (or access) is important, whereas for smallholder irrigation its mainly 'permission to irrigate' that operates.
Supportive policies in place	Medium	Medium	High	Low	Medium	Medium	Supportive policies are required to a certain extent for most of these technologies, but this is high for dambo farming as in some cases this is outlawed or not supported.

NB: [a]This criteria is based on the work of Noble, et al., (2005) which is a (further) breakdown of the 4 typical types of drivers of bright spots success and these are; spontaneity, social , technological and external factors.

With best bet technologies identified, the next task is to outline how these could possibly be up-scaled in the area. Typically with a lot of these technologies, the benefits are known and appreciated, but the difficulties come in making sure that there is sufficient and sustainable adoption of these by the intended beneficiaries, and for those who may adopt, how to further enhance up-scaling. This is normally answered by the classical question of "…*what incentives need to be in place for the uptake and up-scaling of technologies by smallholder farmers*"? A lot of developmental agencies have grappled with this question but the one dominating theme has been to try and link the smallholder farmers with the commercial side of business, i.e., linking them with markets. The classical example is one from Machakos (Kenya) under the then so-called 'more people less erosion' argument by Tiffen, *et al*., (1994) whereby because smallholder farmers' production was strongly linked to markets for their produce, they were able to look after the land and maintain its productive capacity, even though there were many more people per unit area (a recipe for accelerated erosion to take place!). More recently examples exist in the region were such technologies have been linked to cash crop production for the market and there have been some successes (Merrey, 2012). Also large scale research activities have taken place with a plethora of high powered institutions (e.g., IWMI, IFPRI, FAO, IDE, SEI) to look at investment opportunities in AWM that have a high potential or likelihood of improving food security and incomes of poor rural farmers (Giordano, *et al*., 2012) under the AgWater Solutions project. That research generated interesting results on factors such as; technology uptake and use decisions of smallholder farmers, benefits of RWH practices, use of pumps to abstract shallow water, and the drivers to smallholder farmers investing in private irrigation systems in Africa and Asia.

Similarly cases have also been noted were such efforts to encourage adoption and up-scaling have come to nought despite all efforts to link technology and production to markets. What this means is that there is no one solution that fits all circumstances because many other factors come to bear on the final result and these could be; local and national policies on produce prices, lack of adequate infrastructure for farmers (including water, land and roads), donor dependence syndrome by the farmers, local and national politics, limited buffering to withstand shocks to the production system, poor knowledge-exchange systems (Levidow, *et al*., 2014) to help farmers consolidate adoption and uptake, just to mention a few.

Looking at the big picture, one is really pursuing the idea of impact pathways analysis, i.e., how to undertake AWMI that will have impact on the beneficiaries. (Participatory) Impact pathways analysis (PIPA) is at the core of the CGIAR's Water and Land Ecosystems (WLE) research (for which the report is part of) to achieve positive gains on the ground, through impacting on decision making of farmers and policy makers. A lot has been written about this under the Theory of Change (TOC) and guidelines have been developed, and the approach was also tried under the Challenge Programme on Water for Food (Phase II) research projects. Moving forward the idea is to use all this knowledge to outline possible adoption and up-scaling pathways for the AWMI in the Chinyanja Triangle.

Table 2 provides a summary of the comparison of the six best bet options in terms of ideal conditions under which an intervention would succeed, the cost of such an intervention and example countries were these interventions have been practiced (as evidenced by relevant references). Ideally Table 1 should also provide an indication of the benefits derived per dollar of investment, as well as cost-benefit analysis, but this is near impossible a task because of the complex backward and forward linkages and the difficulties associated with quantifying social benefits on interventions.

Table 3 gives a comparative analysis of technological characteristics of the proposed best bet options for the Chinyanja Triangle in terms of factors that influence technology (intervention) uptake (adoption) or success

Table 2: Comparison of up scaling of best bet options of AWMI in the Chinyanja Triangle in terms of ideal conditions for the intervention and estimated costs of the intervention

No.	AWM Intervention	Ideal conditions in which intervention is suited	Estimated cost of the intervention (per relevant unit)[a]	Examples of evidence of sustainability or success or longevity (location)	Example references
1	Small scale irrigation with river diversion and storage	Applicable and adaptable to a wide range of conditions: • Soils: coarse to fine textured • Topography: 0.05% to 1% (or more for short furrows) • Typical stream sizes: 2 to 15 l/s per m width • Command area: from 1 ha to 1000 ha • Distance from water source: up to 5 km (to contain development costs)	Variable development cost: • US$10 000 per ha (or more depending on land levelling requirements)	Found in all countries in the sub-region: • South Africa • Zimbabwe • Malawi • Mozambique • Zambia • Kenya • Tanzania **NB**: Most of these are government developed and regularly receive assistance for revitalisation or rehabilitation	Micheal (1981) Savva and Frenken (2002) Inocencio, *et al*., (2007) Svendsen, *et al*. (2011) Merrey (2012)
2	Small scale pressurised irrigation with motorised pumping	Applicable and adaptable to a wide range of conditions: • Soils: coarse to fine textured • Topography: 0% to 15% • Typical application rates: 3 mm/hr (clays)	Costs depend on mode of development: • US$5 000 to 25 000 per ha (or more depending on distance from water source)	Mainly found in: • Zimbabwe • South Africa • Swaziland **NB**: These are also largely supported by government or donors	Micheal (1981) Savva and Frenken (2001) ARC (2003) Inocencio, *et al*., (2007) Svendsen, *et al*. (2011) Merrey (2012)

		to 50 mm/hr (coarse sand) • Operating pressure: 10 m to 4.0 m • Command area: from 1 ha to over 100 ha • Distance from water source: up to 2 km (to contain capital development costs)			
3	Dambo irrigation farming	Widely applicable: • Water: Existence of shallow water table • Water depth: up to 5 m during the dry season • Topography: 0.8% to 3.5% • Soils: medium to fine textured • Command area: depends on extent of wetland but could be tens of ha	Generally no 'formal' development costs, but the gradual investment by the farmers over time. Costs include: • Land preparation • Sinking of shallow wells • Purchase of treadle pumps, if required (US$50 to US$100 depending on type)	Widely practiced in the following countries: • Malawi • Tanzania • South Africa • Zimbabwe • Zambia	Dambo Research Unit (1987) Daka (2006)
4	Drip kits (including drum and bucket	Simple, but limitations exist: • Soils: medium to fine textured • Command area: 15 m^2 (bucket kit) to 1000 m^2 (drum kit). Can also have farm kits that are able to command >1000 m^2	Investment cost vary depending on size: • <US$50 to US$400 (depending on set-up, from 15 m^2 to 500 m^2)	Some successes in: • Kenya • Malawi • Ghana Limited success in the following countries: • South Africa • Zimbabwe	Sijali (2001) Daka (2006) Merrey (2012) Kadyampakeni *et al.*, (2014) Rohrbach, *et al.*, (2006)

		• Operating pressure: 0.5 m (bucket kit) to 5 m (drum kit) • Water quality: <50 mg/l suspended solids, and < 500 mg/l total dissolved solids • Water pH: <7.0 • Water bacterial population: <10 000 (number/ml)			
5	Small reservoirs	Applicable and adaptable to a wide range of conditions: • Site: must preferably have high storage ratio (to minimise construction costs) • Site: must preferably have clay pan or unfractured bed rock to minimise seepage losses • Size: impounded volume less than 1 million m^3 or wall height less than 8 m • Catchment area: 2 km^2 to 5 km^2 • Catchment protection: need catchment conservation to minimise siltation	Costs vary according to method of construction: • <US$1/$m^3$ storage capacity to US$210/$m^3$ storage capacity if constructed using oxen and manual labour • Cost are much higher for development undertaken by mechanised means	Small reservoirs are a common feature: • All over sub-Saharan Africa	Senzanje and Chimbari (2002) RELMA (2005) Sawunyama, et al., (2006)

		problems from soil erosion			
6	Soil and water conservation practices (including conservation agriculture)	The various practices are applicable to a wide range of conditions: • Rainfall: ideally should be above 450 mm per annum • Soils: medium textured to fine textured soil • Climate: arid to humid	Costs are very variable: • From a few US$ for such practices as micro-basins • US$336/ha for practices such as terracing and contouring.	Successful examples of soil and water conservation are found in many places in the sub-Saharan Africa in countries such as: • Ethiopia • Tanzania • Malawi • Zimbabwe • South Africa (including very success uptake by commercial farmers)	Noble, *et al*., (2005) Mati (2007) Oweis and Hachum (2009)

NB: [a]The table should also provide an indication of the benefits derived per dollar of investment but this is a near impossible task in this type of study because of the complex backward and forward linkages and the difficulties associated with quantifying social benefits of interventions. Inocencio, *et al*., (2007) provide a comprehensive analysis of the development costs of various irrigation projects from Africa and Asia.

Table 3: Comparative analysis of technological characteristics of the proposed best bet options for the Chinyanja Triangle in terms of factors that influence technology (intervention) uptake (adoption) or success[a]

Note: Some of the intervention characteristics are better answered as Yes or No, whereas others can be indicated as Low, Medium or High (see Comments/Notes for each key element). **Key**: No = means characteristics is not there or not required, Yes = means characteristic is there or is required, Low = characteristic is low or is not readily realised, Medium = characteristic is moderate or realised in the medium term, High = characteristic is high or readily realised or readily available, Situation dependent = characteristic is not necessarily dependent on the AWMI intervention but on other factors

Technology or intervention characteristics[b]	**Agricultural water management intervention (AWMI)**						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
Complexity	Moderate	High	Low	Low	Moderate	Low	Dambos, drip kits and soil and water conservation are generally perceived as simple technologies, whereas smallholder technology can be daunting depending on the scale.
Divisibility	Moderate	Low	High	High	Moderate	High	Smallholder irrigation is not easily divisible because it is normally designed as a single entity in terms of the infrastructure, whereas dambos, drip kits and soil and water conservation technologies are readily divisible.
Compatibility	Moderate	Moderate	High	High	Moderate	High	Smallholder irrigation is normally introduced to farmers by government and donors whereas dambo are indigenous technologies, and drip kits can easily be adapted to fit farmers' situations making them much more compatible.

Acceptability	Moderate	Moderate	High	Moderate	Moderate	High	As with any technology when introduced, its acceptability tends to start off slow and then increase once farmers gain in confidence (the so-called concept of 'diffusion of innovations')
Trialability	Low	Low	High	High	Moderate	High	It's generally not easy to try out some individual aspects of smallholder irrigation, but one can try out aspects of drip kits or soil and water conservation practices.
Observability	High	High	High	Low	High	moderate	With the exception of drip kits, for all the other interventions the results are easily observable and can make an impact at once (positive or negative).
Cost	High	High	Low	Low	Moderate	Low	See Table 1 for cross referencing on costs
Profitability	Moderate	Moderate	High	Low	Moderate	Moderate	It all depends on the cropping enterprise, market access and attendant costs of production. Dambos tend to be low cost interventions with decent profit prospects. Drip kits tend to be small and so the profits are also low (in a relative sense).

NB: [a] This is based on the work of several authors that include; Rogers (1995), Cornish (1998), Kuypers *et al*. (2005), Brhane *et al*. (2006), Knowler and Bradshaw (2006), Damanpour and Schneider (2008), Erenstein et al., 2008, Tesfahuneg and Wortmann (2008) , Thiefelder (2013), among others. Strictly speaking these characteristics have to be linked to the socio-economic conditions of the communities or individuals to which the technology is being purveyed. [b]The technology characteristics are briefly defined as follows: *Complexity* = ease or difficulty in the understanding of an intervention, *Divisibility* = ability to use subcomponent(s) of the innovation or intervention package, *Compatibility* = the ease with which an innovation or intervention can be adapted to fit the resources, existing beliefs and values of the farmers , *Acceptability* = the adoption prospects of intervention or innovation when still in the inception stage, *Trailability* = the degree to which a certain aspect of a technology or intervention can be experimented on, *Observability* = the degree to which the results of the intervention or innovation are visible to others, *Cost* = how much it costs to adopt/uptake and implement the intervention, *Profitability* = the yield increase and profit realised after the adoption of an innovation.

3.4.1 Up-scaling small scale irrigation with river diversion

As has previously been discussed, small scale irrigation is known to most smallholder farmers. This type of irrigation tends to have low operational costs, but because it is based on canal water conveyancing and distribution it has low overall efficiencies. This type of irrigation can be up-scaled through:

- support from government and development agencies that could assist in infrastructural development and revitalisation, together with farmers so that they have a sense of ownership
- water management institutions, such as WUAs or IMCs, would then need to be established and empowered (formally or informally), and
- farmers trained in irrigation water management, infrastructure maintenance and crop production.

Typically such schemes would focus primarily of food crop production and any surplus could be sold to generate. Every so often, government may need to come in and assist in infrastructure rehabilitation.

3.4.2 Up-scaling small scale irrigation with motorised pumping

Small scale irrigation with motorised pumping has been successfully practiced in many places in African and Asia. The development and management could follow the model of the small scale irrigation with river diversions. What is important with this AWMI is to realise that it has relatively high operational costs due to pumping (fuel or diesel), and as such:

- it must have a strong component that links it to cash crop production and the markets,
- crops grown should be of a horticultural nature and have a ready market,
- part of the training that the farmers should receive must focus on viable production and marketing strategies to make sure that there is adequate cash generation to pay for the pumping costs,
- some of the marketing arrangements could also entail entering into contract farming (e.g., with tomato canners) which may have slightly low returns but guarantees a ready market for perishables like tomatoes.

Once such small scale irrigation is up and running, it tends to be self-perpetuating with the contractor in some cases even providing inputs (like fertilisers, seed, agro-chemicals) to the farmers. This would almost ensure significant up-scaling.

3.4.3 Up-scaling dambo (irrigation) farming

Dambo irrigation farming is an indigenous technology that has been practiced for many years in southern Africa and only needs a little bit of support. As with indigenous systems, it should not be tempered with too much otherwise the delicate balance set locally may be upset. Dambo farming depends to a large extent on ensuring that the ecosystem goods and services (EGS) of wetlands are kept in balance and environmental concerns are taken into account. Up-scaling of dambo irrigation farming would entail:

- enforcing sustainable watershed management that takes into account environmental protection and biodiversity conservation, since dambo farming is so dependent on it,
- allowing farmers to form farmer groups that would assist with purchasing of production inputs and other requirements,
- train farmers to undertake sustainable farming methods within the context of dambo vlei dynamics, and
- link production to markets so that the farmers are incentivised with the income.

It must be stressed that success of dambo farming could very well be its undoing because if too many farmers join, the resources maybe depleted leading to a collapse of the delicate balance required. In an effort to ensure equity in accessing dambo farming resources, farm holding sizes may need to be reduced, but this will have to be done in the context of local politics.

3.4.4 Up-scaling drip kits (including drum and buckets) irrigation with treadle pumps

Drip kit irrigation could be up-scaled if it is linked to specific production practices. Because of the limited area commanded by some of the units (e.g, bucket kits), production should probably be limited to producing specific crops for household nutrition and production of special (medicinal) herbs and the like. Given the past efforts of FAO, IFAD and even DfID, one is sometimes left at a loss as how to best propose up-scaling of drip kit irrigation in the Chinyanja Triangle. The following is however proposed:

- water must readily be accessible for use with the drip kits, hence it is proposed that use be limited to areas with shallow water tables were water could easily be lifted with low head treadle pumps,
- farmers would need training in how to undertake crop production under drip, i.e., appreciate that even though the soil is not 100% wet, the crops are still getting adequate water,
- farmers to get specialised training in the management of drip technology, especially how to eliminate or minimise drip emitter clogging problems, and
- it may help to have farmers irrigate as groups even though they will be having individual kits to try and get synergies from positive group mentality.

There is probably a lot more learning required with this technology, especially if it is being pushed by NGOs and other humanitarian efforts because results have previously been disappointing (Rohrbach, *et al.*, 2006).

3.4.5 Up-scaling use of small reservoirs

Small reservoirs offer opportunities for up-scaling given their multiple use nature, although conflicts can obfuscate this great potential. Up-scaling should take into account the following:

- harmonious management and use of a common resource to try and balance access and equity issue as well as varied interests,
- promote non-consumptive water uses like fishing, aquaculture and recreation,
- strike a balance between crop production and livestock watering demands,
- promote efficient water use so that more farmers can benefit, and

- setting up management structures that can quickly and effectively resolve conflicts, if such arise.

Small dams are generally low maintenance and, with proper catchment management can have long useful lives, sometimes in excess of 60 years.

3.4.6 Up-scaling soil and water conservation technologies (including conservation agriculture)

As in the case with drip kits, a substantial amount of effort has previously been put into enhancing adoption of SWC technologies and practices by; farmers, governments, international donor organisations, NGOs and development agencies. An important lesson maybe learnt from how CA was quickly adopted by commercial farmers in South and farmers in general in Brazil. In a nutshell, CA was widely adopted because of financial (economic) savings by farmers. How can this also be translated to the smallholder farmer of the Chinyanja Triangle? The following is suggested:

- understand farmer characteristics that would enhance adoption of SWC practices and make sure these are in place, e.g., farmer training, farmer resource capacitation, and policies that may promote subsidies on agro-chemicals for CA, and
- understand technology attributes that promote adoption, such as, cost, low risk if it fails, quick return on investment, and tangible benefits.

Obviously the two points raised above mean a lot and also require much more to operationalise.

Table 4 provides a socio-economic consideration of the proposed best bet option for up scaling in the Chinyanja Triangle. The summary given is only indicative of the farmers' characteristics and can only be used after a proper assessment of the smallholder farmers in the Chinyanja Triangle.

Table 4: Socio-economic considerations[a] of the proposed best bet option for up scaling in the Chinyanja Triangle

Note: The farmers' characteristics are indicated as important (significant) or not important (insignificant) with respect to a given proposed intervention. Alternatively, the importance (significance) of a farmer's characteristic is flagged as low or moderate or high, depending on the perspective.

Farmer characteristics[b]	**Agricultural water management intervention (AWMI)**						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
Access to finance	Important Moderate	Important Moderate	Important Low	Not important Low	Important Moderate	Not important Low	Access to finance is important for intervention and operations thereof. Drip kits tend to be low cost undertakings, so access to finance may not be that important. Regarding soil and water conservation, it all depends on the interventions as some require access to finance, e.g, conservation agriculture (to purchase herbicides).
Managerial aptitude	High	High	High	Low	Moderate	Moderate	Smallholder irrigation and dambo farming requires managerial skills to success. Small reservoirs and soil and water conservation can do with moderate levels of management .
Resource endowment	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Smallholder irrigation is government funded so farmers need not be highly resource endowed. Drip kits are low cost so farmers can manage even if they are not really well resource endowed.

Access to information	Important	Important	Important	Not important	Important	Important	Access to information is important to most interventions so that farmers can understand and take up the best practices.
Institutional environment	Important	Important	Important	Not important	Important	Important	A supportive institutional environment is important for interventions to succeed with exception of drip kits.
Farmers' perceptions	Important	Important	Important	Important	Important	Important	Farmers' perceptions of the interventions are important in its uptake and subsequent sustainability.
Farmers' preference	Important	Important	Important	Important	Important	Important	What farmers prefer normally gets taken up and succeeds.
Farmers' knowledge (education)	Moderate	Moderate	Moderate	Low	Low	Low	Knowledge, like access to information, is important for smallholder irrigation and dambo farming. It may be considered low for drip kits, small reservoirs and soil and water conservation.
Farmers' attitude	Important	Important	Important	Important	Important	Important	Attitudes are important throughout otherwise the interventions may not be taken up.
Labour	High	High	High	Low	Moderate	Moderate	Operations in irrigation schemes tend to be labour demanding, whereas it's low for the small scale drip kits. Regarding soil and water conservation, labour demand is going to depend on the practice, some like terracing require substantial labour.

NB: [a] These are farmer or community considerations that are thought to have an impact on adoption or uptake of acceptance of technologies or interventions introduced. These are based on work of authors that include; Pattanayak, *et al*. (2003), Smit and Wandel (2006), Johannes, *et al*. (2012), Jara-Rojas *et al*. (2012), Meijer, *et al*., 2014, to name just a few. [b] Literature on the Chinyanja Triangle (e.g., Akinnifesi *et al*. 2006; Twomlow *et al*. 2008, Tilahun Amede *et al*. 2014) indicates that the people of the area are some of the poorest in the world, and the communities are characterised by poor access to markets, limited institutional support, lack of investment, and overall deterioration of livelihoods. It is on this basis that the above analysis is undertaken.

4 Agricultural Water Management Interventions Research Agenda for the Chinyanja Triangle and Link to Integrated Agricultural Systems Research

In conclusion to this report an effort in made in this section to high light in summary research issues that may need to be followed in the Chinyanja Triangle and how these link to the Integrated Agricultural Systems Research (IARS). Most of the research issues summarised here arise from the analysis of prospects for sustainable agricultural intensification discussed in the previous sections. Some of the research topics discussed do not fall under the six best bet technologies and practices shortlisted in this report, but are worth exploring for understanding the big picture and future applications. The identified research topics further add and complement the list of priority research issues in the Mutiro and Lautze (2014) report. A key underpinning factor to the research agenda is that it must be both research for development (R4D) and research for action (R4A). The research agenda for AWMI in the Chinyanja Triangle is discussed in the following sections.

Systems approach assessment of constraints to sustainable agricultural development in the Chinyanja Triangle

Using a systems approach, research should investigate the constraining factors to sustainable agricultural development in the Chinyanja Triangle. The factors to be assessed would range from physical (soils, water resources, land degradation, pressure on resources like land, etc), economic (poor rural infrastructure, limited access to markets, lack of access to low cost finance, etc), socio-institutional (weak governance structures, poor extension services to help deliver new innovations and technologies to farmers, conflicts over limited resources, gender based constraints, etc), technical (lack of access to mechanisation programmes, lack of access to technologies like drip irrigation, etc), and agronomic (lack of access to fertilisers and improved seeds, identifying cropping enterprises suited to the area, etc). There will be a need to quickly understand what constraints exist in the area and how these can be circumvented or dealt with to enable conditions to become amenable to rural development through agriculture.

Analysis of farmer attributes that enhance the uptake or adoption of AWMI

It is imperative that the attributes of the farmers are studied to understand these vis-à-vis the requirements for sustained uptake of AWMI technologies and innovations being promoted in the area for rural development. These analyses must be undertaken in the context of integrated systems approaches, i.e., understand farmers' circumstances both as communities and also the environment within which they operate and what constraints they face. The focus should be on getting farmers to be agents of their own development rather than solely being recipients of aid because then they might develop a dependency syndrome.

Analysis of development opportunities available in the Chinyanja Triangle

In line with the systems approach, research should be undertaken to analyse the types and range of developmental opportunities and livelihood strategies exist in the area. Although the focus in this report has been on AWMI, other possibilities such as mixed crop-livestock systems, livestock farming, mixed-tree-livestock systems and aquaculture should also be explored. Some of these systems should aim to incorporate conservation agricultural practices. A wider range of development opportunities are always a good thing as they offer variety and an element of buffering should one enterprise fail then farmers can fall back onto alternative livelihood strategies.

Assessment of the suitability of the proposed AWMI to the Chinyanja Triangle

In line with the proposed best bet AWMI options, these need to be assessed based on the characteristics of the area and its people. As it is at the moment, the proposed best bet options were derived based on literature review, so there is a need try and assess or tie them to conditions that are found in the area.

Research into hardware vs. software components

Technology without adequate software (institutions, people, policies, etc) support is unlikely to succeed. There is thus a need to provide an enabling environment and this implies investing in software issues. Research is therefore needed in the type of software issues that need attention and these may include training smallholder farmers in entrepreneurship, sustainable water management in a commercial environment, responding to market forces, developing proper institutions for conditions existing on the ground in the Chinyanja Triangle, and training service agencies to respond quickly and appropriately to farmers' needs. Policy research is particularly important since more often than not policy and institutional constraints work against adoption of productive technologies and practices.

Analysis of gender related constraints to accessing new opportunities and options

Since women do most of the farming activities in the region, analyses of gender related or gender-based constraints to accessing new opportunities, practices or options is required. Once these constraints are identified ways to deal with or overcome these constraints will need to be developed so that women, children and vulnerable groups can have access to production and livelihood opportunities for the benefit of whole households.

Research into acceptability and adoptability of drip kit technology in the Chinyanja Triangle

As proposed by Merrey and Langan (2014) action research through participatory diagnostic appraisal of actual practices using the Participatory Rapid Diagnostic and Action (PRDA) Planning for Irrigated Agricultural Systems is required to; test the performance and acceptability of some of the bucket/garden drip kit technology, test implementation strategies for these technologies and crop production choices, and adapting available training modules and curricula to specific conditions in the area.

Research into sustainable dambo irrigation farming

Although a lot of research has been done for dambo irrigation, site specific research to understand water balance dynamics and potential for use of the dambo, studies are required on how communities can equitably benefit from limited dambo irrigation opportunities, and research is also required into sustainable watershed management models (for resource poor communities) so that the EGS from dambo irrigation is not upset or lost.

Application of the TAGMI (or its variation) model

An interesting research exercise would be to attempt to apply the TAGMI model to the technologies that have been identified for the Chinyanja Triangle to try and find out which ones have a high likelihood of success if implemented in the area. This could then be used as a guide to which technologies should be tried first.

Researching on out-scaling of SAI options in AWMI

In line with research on constraints analysis, research is required to identify opportunities for successfully out-scaling AWMI in the Chinyanja Triangle. For example, what conditions need to be in place for a particular AWMI to be out-scaled? If this is understood through research then such conditions could be created or enhanced so that that innovation or practice can be out-scaled. Normally out-scaling requires multidisciplinary participation of various experts and specialisations.

In summary, the identified research problems contribute directly and indirectly to the bigger goal of the CRP-WLE IARS agenda, particularly the focus on SAI based on AWMI.

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APPENDIX A

Table A1: Comparative analysis of possible agricultural water management interventions (AWMI) for the Chinyanja Triangle (list excludes small reservoirs)

No.	Agricultural Water Management Intervention (AWMI)	Key Advantages[a]	Key Disadvantages[a]	Role of the Smallholder Farmer[b]	Prospects of Applicability[c] to the Chinyanja Triangle	Some Pertinent References
1	***Irrigation based AWMI***					
1.1	Large scale commercial irrigation (LSCI)	• Offers (development and operational) economies of scale • Can enhance national economic development through cash crop production for export • Promotes rural infrastructural development • Can ensure national food security • Can grow crops for import substitution • Increased government revenue through various taxes • Increased value of land	• Negative environmental effects (salinization, water pollution, etc) if not properly planned • Negative social impacts (loss of land and water, social upheaval) if not properly planned • Land grabs can be exploitative • Can be a drain on the government fiscus if they need financial bail out	• Labour provision • Employment prospects • Opportunity for being a shareholder in a commercial irrigation enterprise	***Limited*** because: • Scale of operation is not generally for smallholder farming • Scale of development requires resources not available to smallholder farmers	Merrey and Sally (2008) Woodhouse (2012) Grain (2012)

1.2	Smallholder communal irrigation – river diversion or pumped water supply	Government initiated • Better planned and laid out infrastructure • Formal scheme management structures (by-laws) • Smallholder farmers derive benefits of government assistance • Operations can run smoothly to the benefit of all if by-laws are followed	Government initiated • No sense of ownership by farmers (seen as a government project) • Infrastructure can easily be run down due to delayed action from action • Reliance on government for scheme maintenance • Inefficient operation inherent in government run schemes • Most such schemes fail to live up to expectations • High probability of farmer conflict as they may not have a common agenda • Tend to have operational sustainability problems	Gvt initiated • Primarily as farmers • Can provide labour Farmer initiated	Gvt initiated ***Good to high*** because: • This irrigation development model is known to most governments • Irrigation offers visible or tangible benefits to the electorate • Easily justifiable to donors • Easy for feasibility studies to return a positive internal rate of return (IRR) Farmer initiated	Va Averbeke *et al*., (2008) Vernot *et al*., (2012)

		<u>Farmer initiated</u> • Farmers have sense of ownership • Tend to be viable through growing high value crops • Technology matched to farmers needs • Group cohesion as farmers generally have a common agenda	<u>Farmer initiated</u> • Poorly laid infrastructure because of limited resources • Runs the risk of abandonment if other livelihood opportunities arise • High exposure to the vagaries of both the weather and the economy • Conflicts among irrigators in the absence of group cohesion	• Opportunity to be a farmer • Can also be a worker	<u>***Good to high***</u> because: • Currently most donors prefer this irrigation development model • For a determined (committed) group of farmers, this type of irrigation development will take place	Giordano *et al*., (2012) InnoWat (2014)
1.3	Smallholder individual irrigation	• Individually operated system without the problems of many farmers • Driven by individual motivation to succeed • Can be complete and self-contained (water source to field operations) • Farmer may have freehold title thus able to borrow	• Depending on size, may have problem of economies of scale • Viability concerns unless if they grow high value crops • Conflicts over access to water may arise depending on water permit	• Role of a farmer • Also can create employment opportunities for others	<u>***Moderate to good***</u> because: • Farmers in Chinyanja are not likely to have freehold title to land • Socio-economic setup in Chinyanja may not encourage relatively	Merrey (2012) Postel (2013)

		money for development and operation costs • Maybe linked to large scale commercial irrigation as an ‘out grower’ and benefit from economies of scale			large individualised units, but possibly small units • Prospects for individual food security are good	
1.4	Smallholder communal sprinkler irrigation	• Adaptable to individual or group irrigation • Better water control and more efficient water application • Can be designed for on-demand irrigation, e.g., drag line irrigation • Centre pivot irrigation lends itself to ‘estate type’ dedicated management and operation and farmers being like shareholders, e.g., smallholder farmer sugar cane irrigation in Swaziland	• Relatively high capital development costs (per unit area) compared to flood irrigation • Comparatively high running costs due to pumping requirements • Generally high equipment maintenance cost and need for reliable back-up services • Equipment must be depreciated and resources put aside for its replacement as and when due	• Opportunity to be a farmer • Opportunity for employment in irrigated agriculture • Opportunity to provide equipment repairs and maintenance services to farmers	***<u>Moderate</u>*** because: • Sprinkler irrigation not commonly used in smallholder group irrigation except under special arrangements • Tends to be problematic with regard to equipment security • Has problems of relatively high operation costs due to pumping for system pressurisation and this negatively impacts on	Msibi *et al*., (2014) Mutiro (2015)

		• Normally sprinkler irrigation is considered advanced irrigation technology by farmers	• Conflicts can arise over equipment sharing • Disagreements can arise over crops to be grown under shared irrigation equipment • Security concerns over equipment theft (aluminium pipes, brass sprinkler heads)		financial viability of operations	
1.5	Smallholder communal drip irrigation	• High application efficiencies • Better water and fertiliser use by crops • Potential for system automation and therefore reduced labour requirements • Irrigation uniformity not affected by wind • Drip is suited to the irrigation of high value crops, e.g., tomatoes, green peppers, onions and other	• Relatively high initial capital development costs (compared to sprinkler or flood irrigation) • Drip technology has high water quality management requirements • Drip is not applicable for the irrigation of low value crops like maize and wheat • Drip is not applicable to the irrigation of	• Role of farmer • Employment creation • Service provision to the farmers, e.g., equipment maintenance	***Low*** because: • Drip is not adaptable to the irrigation of low value crops common in smallholder irrigation • Drip has high initial capital development costs per unit area • Drip technology is not common to smallholder irrigation • Drip requires efficient water	

		vegetables, as well as fruit trees	coarse textured soils common in many small holder irrigation schemes • Drip equipment is easily prone to damage as it is mainly plastic • Drip emitters easily clogged if water filtration is not good • Field operations are impeded by permanently installed equipment • Conflicts may arise if farmers do not follow block irrigation as is typically designed for under drip irrigation		quality management to prevent emitter clogging problems	
1.6	Drum and bucket drip kit irrigation	• Comparatively low investment cost of the kits • Suited to backyard and small unit irrigation of vegetables crops and specialised herbs for	• Area commanded tends to be quite small for extended food production • Requires manual water lifting to fill the bucket or drum	• Role of farmer	***Good*** because: • Technology is easily adapted to individual home and backyard gardens • Technology has low investment costs that are	Daka (2006) Rohrbach, *et al*., (2006) Kadyampakeni, *et al*., (2014) Merrey and Lagan (2014)

		nutritional supplement • Compact size allows for easy management by individual families • Operate at very low head (pressure) thus have low operation costs • Equipment easily portable	• Generally require availability of shallow water sources and water lifting technology • Because of its portability, the equipment is prone to theft and needs to be secured • Emitters easily clog if water quality is not assured • Drip buckets and drums find alternative uses to irrigation, e.g., used for water storage in the home.		affordable by many • Technology is simple enough and does not require extensive knowledge to operationalise it • Suited to specialised crop and herb production for specific needs, e.g., nutrition and medicinal	
1.7	Moistube irrigation (MTI)	• Delivers water and fertilisers directly to crop root zone • Provides water to crops at the rate at which they use the it • Does not require emitters but uses advanced	• Not much is known about this technology in the sub-region • Not sure how much area can be commanded per given design • No knowledge of range of crops that can be	• Irrigator	***<u>Low</u>*** because: • This is an untried and untested technology that would need to be introduced to the irrigators in the area	Irrigation (2011)

		membrane technology • Has no problems of emitter clogging	irrigated by the technology • No knowledge on soil water dynamics under MTI			
1.8	Dambo irrigation farming	• Indigenous practice that has been around for quiet sometime • Allows late (end of summer) and early (end of winter) crop establishment • A wide range of crops can be grown under dambo irrigation, from maize to vegetable crops • Allows for supplementary irrigation through use of shallow wells • Offers increased crop intensities • Potential for increased yields • Has low operational costs	• Conflict by various users on access to dambos, e.g., for crop production • Conflict on the use of the dambo resources for different uses, e.g., crop production vs. livestock grazing • Requires the maintenance of a delicate balance on the use of the dambo vis-à-vis natural recharge • Risk of dambo drying out in excessively dry years • Old and outdated legislation in some places outlaws dambo cultuvation	• Role as a farmer • Employment creation	***Good to high*** because: • Dambo farming is and age old tried and tested practice that farmers are familiar with • Offers low cost opportunities for agricultural intensification	Daka (2006)
2	***Soil and water conservation (SWC) and conservation agricultural (CA) interventions***					

2.1	Soil and water conservation practices	• Technologies tend to be simple and do not require extensive knowledge • Technology help in conserving soil and moisture • Generally technologies require minimal inputs • Technologies are applicable over a wide range of farming scales (smallholder to large scale) • Benefits are easily observable and tangible in most cases, e.g., improved crop performance • There is a wide range of SWC technologies that suit different soil and climatic regions	• Some of the SWC technologies are labour intensive at initial set-up, e.g., construction of bench terraces requires 100 to 300 person-days per ha • Uptake usually requires a paradigm shift in the farmers	• Opportunity to be a farmer • Opportunity to provide labour	***Good*** because: • The benefits of properly implemented SWC are easy to see and appreciate • Technologies tend to be simple and have minimal inputs • Some of the technologies can be considered as indigenous practices, e.g., terracing, and so don't need extensive investments • Technologies are suited to the scale of farming operations in Chinyanja area	Mutekwa and Kusangaya (2006) Daka (2006) Mati (2007) Merrey and Sally (2008) Rockstrom, *et al.,* (2010) Andersson and D'souza (2013)
2.2	Conservation agricultural (CA) practices	• Considered a win-win situation • Minimises soil disturbance	• CA is considered a complex technology	• Opportunity to be a farmer	***Moderate*** because: • It is difficult for smallholder farmers to leave	Baker, *et al.,* (2002) Perret and Stevens (2003)

		• Ensures soil is permanently covered • Encourages the practice of reasonable crop rotations • Provides visible benefits in soil fertility and soil moisture management	• CA requires a change in the mind-set of the farmer • CA is considered knowledge intensive • Uptake to date by smallholder farmers has be low to disappointing	• Opportunity to provide labour	trash on the ground as this is consumed by animals during winter • There serious problems associated with weed control by smallholder farmers under CA • There is a genuine need for farmers to have a mind shift to accept and begin practice CA	Hobbs, et al., (2008) Giller, *et al.*, (2009)

NB: [a]The key advantages and disadvantages presented in this comparison table are contextualised to the conditions in the Chinyanja Triangle (see Section 1.1). [b]For each AWMI, the role that the smallholder farmer could play is given. In most cases they would be farmers deriving livelihoods from the intervention, but in some cases the smallholder farmer can be provide labour or a service to irrigators. [c]Each technology is then weighed or analysed on the likelihood of it being applicable to the Chinyanja Triangle, given the conditions therein as outlined in Section 1.1. Due to the low resource endowment of the people in the area, capital intensive interventions have a low to moderate prospects of being applicable. However, in cases were the government or donors could provide development assistance, e.g., smallholder irrigation, the prospects of such interventions being applicable to the Chinyanja Triangle are upped.

Table A2: Comparison of best bet options up scaling impacts of AWMI in the Chinyanja Triangle following the concept of 'Theory of Change'

No.	Inputs (the interventions)	Potential outputs	Potential outcomes	Possible impacts
1	Small scale river irrigation with river diversion	• Timely management of blue water resources • Manageable and affordable irrigation practices • Reduced vulnerability to crop production failure • Good potential for multiple use (MUS) of the canal infrastructure	• Farmers adopt better crop production practices under irrigation (water, seeds and fertiliser) • Water is available as and when needed for irrigation • Farmers equipped to operate more resilient production systems • Farmers are able to engage with produce markets • Farmers minimise risk through MUS practices • Farmers transition from subsistence farming to more commercial oriented production	• Improved income from cash crop production • Improved food and nutrition security from food crop production • Improved livelihoods for rural based farmers • Markets and marketing channels developed • Rural development leading to national development
2	Small scale irrigation with motorised pumping	• Better water control • Efficient management of blue water resources • Reduced vulnerability to crop production failure	• Farmers adopt better crop production practices under irrigation (water, seeds and fertiliser) • Water is available as and when needed for irrigation • Farmers equipped to operate more resilient production systems • Farmers are able to engage with produce markets • Farmers transition from subsistence farming to more	• Improved income from cash crop production • Improved food and nutrition security from food crop production • Improved livelihoods for rural based farmers • Markets and marketing channels developed • Rural development leading to national development

			commercial oriented production	
3	Dambo irrigation farming	• Effective utilisation of shallow water resources • Longer cropping season • Wide range of crop choices • Women farmer empowerment (and possibly gender equality)	• Farmers are able to operate more resilient crop production systems (through water management and growing a range of crops) • Farmers adopt production practices suited to dambo irrigation • Women farmers become empowered and can engage with produce markets • Farmers become environmentally conscious in working in dambo irrigation (livelihoods depend on sustained dambo farming)	• Improved income from cash crop production • Improved food and nutrition security from food crop production • Improved livelihoods for rural based farmers • Markets and marketing channels developed
4	Drip kits (including drum and bucket)	• Manageable technology for the farmer • Opportunity for specialised crops and herbs production • Empowerment of women farmers and vulnerable groups	• Women and vulnerable groups are empowered to produce specialised crops in backyard gardens • Production is sustained because of simple and manageable drip kit technology	• Improved food and nutrition security from food crop production • Improved health for farmers and vulnerable groups
5	Small reservoirs	• Opportunities for multiple use system (MUS), e.g., crop production, aquaculture, domestic and livestock watering	• Farmers are able to operate more resilient production systems through MUS and better water management (reduce risk) • Empowered women able to demand farming related	• Improved income from cash crop production • Improved food and nutrition security from food crop production • Improved livelihoods for rural based farmers

		• Improved blue water management through irrigation • Empowerment of women through irrigated crop production • Opportunity for a range of crops to be produced	services and engage with produce markets	• Markets and marketing channels developed
6	Soil and water conservation practices (including conservation agriculture)	• Enhanced soil conservation and soil fertility management • Improved management of green water resources • Enhanced resilience to vulnerability of rainfed agriculture to the vagaries of the weather	• Soils have more productive capacity • Rainwater is effectively utilised on the land where it falls • Resilient farming practices possible through better soil and water management • Farmers empowered through improved production of food crops (and any surplus for sale)	• Improved income from cash crop production • Improved food and nutrition security from food crop production • Improved livelihoods for rural based farmers