UNIVERSITY OF ZIMBABWE

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

THE INFLUENCE OF RAINFALL SEASON QUALITY ON MAIZE YIELD UNDER CONSERVATION AGRICULTURE ON SOME SELECTED LOCATIONS IN MALAWI

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August 2010

In collaboration with

The Influence of Rainfall Season Quality on Maize Yield under Conservation Agriculture on Some Selected Locations in Malawi

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A Thesis Submitted In Partial Fulfillment of the Requirements of Masters Degree in Integrated Water Resources Management

ABSTRACT

Conservation agriculture (CA) is becoming an important option for integrated land and water resources management in most parts of the Sub-Saharan Africa region. Minimum soil disturbance, maximum soil cover, and crop rotations are the cornerstones of CA. The popularity of conservation agriculture is growing because, not only does it promise to improve yields, it simultaneously improves the environment from which the food crops are being produced. The former being important for Millennium Development Goal number one and the latter for goal number seven. An attempt was made to contribute towards the advancement of the CA technology, by defining the rainfall season quality in which CA would produce optimum yields for maize. Implementing CA within this rainfall season quality would enhance efficient utilization of rain water. Efficiency is one of the cornerstones for attaining integrated water resources management, both at the catchment and basin level.

The Water Requirement Satisfaction Index, computed using the AgroMetShell, was used to characterize rainfall seasonal quality. The characterization was in such a way that as the index approaches 100, the quality of that season is considered very good and crop performance is expected to be approaching its potential.

The average grain yield for maize and rainfall records for 34 farmers from 6 districts in Malawi, namely, Balaka, Dowa, Machinga, Nkhotakota, Salima and Zomba were used. The rainfall season quality at Extension Planning Area (EPA) and at farmer level was established for these 34 farmers. The interpretation that yield increases with an increase in the WRSI was tested both at EPA and farmer level. The average grain yield from conservation agriculture was compared with that from a conventional farmer's practice at a given rainfall seasonal quality.

At EPA level, it was found that only in 1 district, Salima, did crop performance increase with an increase in the WRSI. This increase however was not statistically significant. At farmer level, 10 out 26 crop performances followed the interpretation of the index. Out of the 10, only 1 crop performance, for Dowa in 2009 was statistically significant at p=0.05.

There was no significant difference between the average grain yield obtained from conservation agriculture and the average grain yield obtained from conventional farmers practice, at a given rainfall season quality. However the yield gains from CA in relation to farmers' conventional practice increased with time.

The Water Requirement Satisfaction Index was thus found not to be the most suitable tool for advising whether CA can be implemented in an area or not in Malawi.

Key words: conservation agriculture, rainfall season quality, Water Requirement Satisfaction Index.

DECLARATION

I hereby declare to the Senate of the University of Zimbabwe, that this dissertation is a product of my own investigation except whereby acknowledged, and that it is being submitted for the degree of Master in Integrated Water Resources Management (IWRM). I also declare that the interpretation of the results from the data collected are entirely mine and based on the period that I collected the data. Additional data collection and analysis by a different person may result in different interpretations.

KUFASI SHELA……………………………………………………………………………….

Name and Signature   Date

DEDICATION

This thesis is dedicated to Siyabonga Shela Phiri. My boy, we are going to be alright.

And to Tiwonge Chiphanga Shela……..

ACKNOWLEDGEMENTS

I would like to thank my Jehovah Ebenezer, who has brought me this far.

Rev and Mrs Kapachika, and Katando CCAP Youth for releasing me with a blessing into Zimbabwe.

Pastor Thom and Bonnie Deuschle and the entire Celebration Ministries International Family; Pastors Jonny and Doret Basson and the entire Christian Celebration Church, thank you for walking with me through out my school.

To my parents, for encouraging me to come to Zimbabwe, at a time like this, when everyone else was against it.

Thank you Dr Martin Ager (FAO) for introducing me to WaterNet. WaterNet thank you for this Masters scholarship. It was an honour.

To Dr Isaiah Nyagumbo, thank you for the support. Prof. H.R. Mloza Banda I will never know why I mattered so much, but thank you for working harder than me. Dr. Eng. H Makurira, you have an amazing way of stirring a person to do more than they thought they could, thank you.

To my Director Mr. J. Mussa, thank you for letting me use the government laptop for this school. Mr Mathews Manda, you showed me the meaning of working hard, thank you. Gertrude Kambauwa, my boss, my mother, my friend.

The IWRM class of 2009, you have taught me true meaning of integration. Tshepo and Asha the mighty woman of God thank you for being there for me, with me, all the way.

Adams Chavula thank you for your time and instruction on the modeling. Chikondi Makhwiza, Dorothy Tembo, Cliff Phiri, this paper would be without statistics if it were not for you guys! Peter Chari thank you for saving my laptop from many deaths.

My family at Embombeni, Champhira and all subsidiaries, far too numerous to mention, thank you for your support. Ngami, Thandi, Alpho, Jomo, thank you for your support. Muyanga, Munozga, Asante and Maya, you are next!

The data used in this thesis was obtained from : CIMMYT (Harare office) who have been working with Total Land Care and The Challenge Programme in Malawi; the Department of Climate Change and Meteorological Services of the Malawi Government; and FEWSNet Malawi.

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GLOSSARY OF ACRONYMS

AMS	:	AgroMetShell of FAO
CA	:	Conservation Agriculture
CIMMYT	:	Centre for Improvement of Tropical Maize and Millet
EPA	:	Extension Planning Area
FAO	:	Food and Agricultural Organisation of the United Nations
LGP	:	Length of Growing Period
MoAFS	:	Ministry of Agriculture and Food Security
SADC	:	Southern Africa Development Community
UNEP	:	United Nations Environmental Programme
NOAA	:	National Oceanographic and Atmospheric Administration
PET	:	Potential Evaporation
WRSI	:	Water Requirement Satisfaction Index

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Rain fed agriculture remains a source of livelihood for almost 80% of the population in Africa (UNEP, 2006). Yet irrigation, which consumes 80% of the global water resources only produces 40% of food (Ngigi, 2003; Rockström *et al.*, 2003). In sub -Saharan Africa (SSA), it is estimated that 70% of the farmers are smallholders, with land holding sizes of less than 1ha (UNEP, 2006). This smallholder farming however is characterized by crop yields of less than 1 t / ha against a potential of 6 t / ha (Falkenmark and Rockström , 2004). Such low yields have contributed to the majority of these smallholder farmers being trapped in vicious cycles of food insecurity.

Water remains a critical factor for crop production among smallholder farmers in Sub Saharan Africa (Rockström, 1999). Rockström *et al.*, (2003) ascertain that the risk of crop failure due to variable rainfall deters farmers from investing in such aspects as fertilizers, pesticides; thereby reducing the likelihood of higher yields even further. This suggests that availability of water for smallholder farming is critical in determining crop productivity. Unfortunately, there is little that farmers can do on how the rain falls. Points of intervention start when the rain has fallen.

There are a number of interventions through which smallholder rain-fed agriculture can be improved. The interventions include those that deal with improving the inherent characteristics of the crop, such as drought tolerance, disease resistance and yield levels. Other interventions deal with manipulating the soil on which the crop grows. The latter may involve improving the soil fertility or water holding capacities so as to increase the amount of water available for the crop (Falkenmark and Rockström , 2004).

Conservation agriculture (CA) is a land management practice that can be applied to increase the amount of rainwater available to the plant. It involves the simultaneous application of three principles: minimum soil disturbance; maximum soil cover and crop rotations (Temesgen, 2007). The application of CA improves crop production by protecting and enhancing the land resources on which production depends (Dumanski *et al.,* 2006).

Conservation agriculture has a wide application, stemming from the notion that it is not prescriptive. Farmers are at liberty to adopt techniques best suited to their environment as long as they satisfy the three principles mentioned above. This flexibility allows the technology to be applied on a number of crops including wheat, rice and maize; the latter being the focus in this research. This flexibility has at times led to confusion as to what exactly constitutes CA (Giller *et al.,* 2009)

There have been reports from Zimbabwe suggesting that the use of CA in the form of *conservation farming basins* may lead to depressed yields in seasons of above normal rainfall. (Nyagumbo, 2008). Other studies have also shown that in the sub-humid areas north of Zimbabwe, there was no significant differences with CA and non CA in very wet years; but CA was better than conventional systems in dry years (Nyagumbo, 2008). This may suggest that CA operates particular rainfall thresholds, within which it gives optimum returns to investments. Pacey *et al.,* (1986) suggests that areas suitable for runoff farming are those that receive an average annual rainfall of 500 – 600 mm. Conservation agriculture can be classified as part of this runoff farming that Pacey *et al.,* (1986) alludes to, whose optimal performance is realized when annual rainfall is between 500 – 600 mm/annum.

Generally, farming practices that appeal more to the smallholder are those that ultimately increase their yields. Conservation agriculture is being promoted based on the hypothesis that it helps the farmer get higher yields. The definition of whether which CA would be suitable for a particular area can thus not be based on average annual rainfall alone. This definition may have to consider other parameters that influence yield such as the state of the soil, levels of farm management. Even the rainfall itself, has to be carefully defined in terms of duration, onset, cessation and distribution. The process of defining the rainfall thresholds is what is being called characterizing of the rainfall seasonal quality. Where rainfall season quality defines whether a season was good or bad for crop performance; and has been defined following the interpretation of the Water Requirement Satisfaction Index. This characterization looks at aspects of rainfall distribution (e.g how the 500-600 mm/annum mentioned above should be distributed across a season), and how it relates to the actual crop water requirements of maize.

The focus here was narrowed to aspects to do with rainfall and not the other factors that influence yield. This narrowing down was largely influenced by availability of data and the timeframe within which the study for this thesis had to be done.

The Water Requirement Satisfaction Index (WRSI) is a water balance model that roughly measures how well a season satisfied the crop water requirement (Mukhala and Hoefsloot, 2004). The computation of the index divides an entire year into 10 day periods called dekads. Each development stage of a crop will thus fall in a particular dekad. The rain that has fallen in a given dekad is measured against the amount of water a crop requires at a given developmental stage. This measurement is what is computed into the WRSI. A summation is made for all the developmental stages of the crop, to come up with an average for the entire growing season. If the WRSI comes out as 100, that season is characterized as very good and crop performance is expected to reach 100% of its potential. It is this classification that has been used to define seasonal quality in this study.

There are a number of indices that have been developed to define aspects of rainfall with regards to crop performance. For example the Standardised Precipitation Index (SPI) which was developed for defining and monitoring local droughts (Paulo *et al.*, 2002). The SPI was conceived to identify drought periods and the severity of droughts at multiple time scales (McKee *et al.*, 2003); it is not explicit however to define whether a drought is hydrological, meterological or agricultural; the latter being of higher interest in the current study.

The WRSI was thus singled out because it relates to agricultural droughts as it pools a number of factors that interact with rainfall to influence yield. It combines factors to do with soil; crop parameters such as the length of the growing period; and potential evaporation. Secondly the WRSI has been chosen because of the way it relates seasonal rainfall and crop performance. The relationship is both qualitative as well as quantitative. The outputs of the index are quantitative, but their interpretation is both quantitative and qualitative. At index 100, crop performance is expected to be very good (qualitative interpretation) and yield is expected to be >100% (quantitative interpretation) of potential (Mukhala and Hoefsloot, 2004). This combination of a quantitative and qualitative interpretation allows easy interpretation of the index, even for people outside agro-meteorology. An attempt was done to see if the WRSI can be used to advise adoption of conservation agriculture in a given area.

1.2 Research Justification

Malawi is an agro-based country, where agriculture is a source of livelihood for more than 80% of the population. About 60% of this agriculture is rain fed, undertaken by small holder farmers, with land holding sizes of 0.2 to 1 ha (LRCD, 2000). Apart from being the source of livelihoods, agriculture is the single most important sector of the Malawi economy, contributing about 36% of the GDP, employing 85% of the workforce, and contributing 90% of foreign exchange earnings as of 2003. Maize remains the major food crop for the country, with such crops as rice, cassava and banana dominating in some selected parts of the country (MoAFS, 2008).

Attaining national food security is one of the key result areas for the Malawi Growth and Development Strategy (2000), and feeds to the goal of sustainable economic growth. This goal was made in line with the Millennium Development Goal number one of halving the number of people living in extreme hunger and poverty by 2015. Declining soil fertility and climate shocks continue to pose threats to achieving these goals for a country that relies on agriculture for economic growth and food security. The Malawi Government has thus been investing in low cost sustainable land management initiatives to ensure food security and sustainable economic growth.

Conservation agriculture has been singled out by the Malawi Government as a low cost sustainable land management initiative for the small holder farmers. The area under CA (by smallholder farmers) in Malawi has been increasing from 5 ha in 2006 to 30,000 ha in 2008 (LRCD, 2009). Understanding the rainfall thresholds on which CA produces optimum yields would ensure that these farmers, and many others beyond Malawi, utilize their rainwater efficiently. Holding all other factors of production constant, efficient utilization of the rainwater contributes to increased crop yields. This would ultimately contribute to Millennium Development Goal of halving the number of people who are hungry by 2015; and the goal of ensuring environmental sustainability. Efficient utilization of rainwater is also critical in promoting an integrated water resources management approach; which has become a fundamental pillar for sustainable development.

1.3 Research Objectives

Overall Objective:

To explore the influence of rainfall season quality on maize yield under conservation agriculture.

Specific Objectives:

- To characterize rainfall season quality using the Water Requirement Satisfaction Index on some selected locations in Malawi.
- To establish maize yield response to the rainfall season quality as defined by the Water Requirement Satisfaction Index.
- To determine maize yield differences between conservation agriculture and farmer's practice at a given rainfall season quality.

From these objectives, this study is based on the following hypothesis:

- Maize yield will increase with an increase in the rainfall seasonal quality.
- The average grain yield of maize under conservation agriculture is significantly higher than that under conventional farmer practices on some selected locations in Malawi.

Null hypothesis

- Maize yield will not increase with an increase in the rainfall seasonal quality.
- The average grain yield of maize under conservation agriculture is not significantly higher than that under conventional farmer practices on some selected locations in Malawi.

1.4 Scope and Limitations in this Study

This study takes cognizance of the many developments that have taken place within conservation agriculture. It also acknowledges that there is a wide variation between what is defined as conservation agriculture and what is found on the ground. The universal definition however still embraces what are known as the CA principles which are minimum soil disturbance, maximum soil cover and crop rotations/ mixture.

The wide variety in definitions and practices has implications on the interpretation of results from previous research work. For example, Erenstein (2003) reported a study where yield from CA is 73% higher than that from non CA. If this study were to be used as a baseline, it might be necessary to replicate the exact treatments that were employed.

The CA definition used in this study takes the broader definition of the FAO (Dumanski *et al.*, 2006), where a farmer must simultaneously combine the three principles mentioned above in order to obtain significant benefits from the technology. Thus the focus of the study was on the benefits of the CA technology as whole, regardless of the actual practices that a farmer uses to achieve the overall goals of the CA technology.

The second limitation in this study was the availability of consistent maize yield data. This study aimed at analyzing rainfall season quality in relation to maize yield. To achieve this, large data sets were required for rainfall and maize. An ideal situation would have been where rainfall data would come from different zones (*i.e* high, medium and low zones) over say 30-40 years and maize yield for at least 5 years. The yield records available however only covered zones with medium to high rainfall. The farmers were only found in these zones as this was how the projects from which this research data was sourced were designed. The researcher had to make do with these rainfall records as no yield records for conservation agriculture (consistent enough) could be found anywhere else within the study area and the given study period.

Thirdly this study made use of historical data obtained from different sources. It was not easy to verify these data records within the given research period in this study. An ideal situation would have been where the researcher has at least one full growing season to run the different conservation agriculture treatments found in the study area as well as make rainfall recordings.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Principles of Conservation Agriculture

Conservation agriculture (CA) is a farming system that integrates ecological management with modern scientific agricultural production methods. It employs technologies that enhance the quality and ecological integrity of the soil. CA is based on optimizing yields and profits, to achieve a balance of agricultural, economic and environmental benefits (Dumanski *et al.*, 2006).

Conservation agriculture techniques are organized around three principles namely minimum soil disturbance (in some cases also referred to as reduced tillage, minimum tillage or zero tillage), maximum soil cover and crop rotations (Hobbs, 2007). The specific technologies under each of the principles vary worldwide and have resulted in the practice being known under various terms (Derpsch, 2005). The CA concept in Zambia for instance is practiced under the term conservation farming. Typical package for hoe farmers in the Zambia scenario includes retention of residues; completion of land preparation in the dry season; establishment of precise and permanent planting basins; precision use of inputs; early and continuous weeding; and rotations (Langmead, 2005). The use of the term conservation agriculture as an embracing term for no-tillage, conservation tillage, direct seeding and other techniques has improved the understanding of the CA concept in national and international organizations worldwide (Derpsch, 2005).

2.1.1 The Techniques

The techniques in conservation agriculture tend to vary based on the principle they are addressing; their suitability to the farmer and the level of investment a famer can make on the farm (Derpsch, 2005; Giller *et al.,* 2009). Reduced tillage techniques include use of farm machinery that combine operations to reduce soil disturbance, cost and time of operations; use of herbicides for weed control (Rainbow, 2008). Rippers and sub-soilers have become significant as CA machinery for the smallholders due to their ability to open up the soil for greater rainfall infiltration (Mwalley and Rockström, 2003). Planting basins and permanent planting ridges are common minimum soil disturbance techniques among smallholder farmers (Langmead, 2005).

To ensure maximum soil cover, some of the techniques include mulching, the use of cover crops and / or mixed cropping and crop rotations. Crop rotations are done either through the physical interchanging of crops on a piece of land; or through crop mixtures where a legume is incorporated with a non legume crop (Giller *et al.,* 2009). Mulching remains one of the straightforward technique for soil cover though it remains a challenge for most farmers in semi arid savannahs; where biomass to secure year round mulching is hardly available (Mwalley and Rockström, 2003).

2.1.2 Impacts of Conservation Agriculture

Zero tillage (to attain minimum soil disturbance) is the cornerstone of CA and can be practiced by smallholder farmers will relative ease (Dumanski *et al*., 2006). Tillage is a common practice for most smallholder farming systems, but is discouraged in a CA due to a number of factors: the costs associated with machinery and animals; soil compaction; oxidation of soil when exposed by tillage; and it exposes the soil to the impact of raindrop thereby increases the risk of low infiltration, and soil erosion (Hobbs, 2005).

Zero tillage mainly involves reducing the number and intensity of tillage operations. Its benefits include: improved soil health thereby improving infiltration; reduced time and labour requirements; reduced weed populations over time and increased yields (Hobbs, 2007). In Brazil, a study showed that zero tillage increased yields of maize (+20%), onions (+26%) and *phaseolus* beans (+ 30%) among smallholder farmers (Derpsch, 2005).

Zero tillage has also been observed to increases water-use efficiency, with water savings of 15-50% in irrigation systems (Hobbs, 2007). The amount of grain yield produced from 1 mm of rainfall increased from 2.6 kg to 7.4 kg when farmers shifted from conventional practices to conservation agriculture (Mwalley and Rockström, 2003). This shift involved moving from ploughing under poor soil fertility management to reduced tillage through ripping under improved soil fertility management.

A combination of zero tillage and permanent soil cover increases water infiltration; reduces the shocks of drought stress and decreases soil and water erosion (Hobbs, 2007). In semi-arid regions mulching has been shown to reduce the risk of complete crop failure at field level due to better capture and use of rainfall. In semi-arid and dry sub-humid locations in East and Southern Africa minimum-tillage practices increased water productivity and crop yields, even with minimum mulch (Rockström *et al*., 2003). In Tanzania, ripping without any kind of soil nutrient management resulted in 60% yield increase to an average of 2.5 t/ha, which was higher than the expected 1 t/ha. The highest yield gains in the same area however came when soil nutrient was managed, which resulted in 240% yield gain with an average grain yield of 3.9 t/ha (Mwalley and Rockström, 2003).

The use of the Row Planter, an implement specifically modified for conservation tillage in maize was studied in Ethiopia by Temesgen, (2007). The study showed that the row planter resulted in early and twice as much seedling emergence compared to manual placement of seed. Temesgen, (2007) reported that higher seed germination was more pronounced under moisture stress conditions. This modified row planter contributed to farmers having increased grain yields; as well as savings in labour and time of up to 85%. In Tanzania, it was found that women could afford as well as save labour by tilling their land while it is still dry, and well before the onset of the rains (Mwalley and Rockström, 2003).

Erenstein, (2003) reported results of on farm trials done in Jalisco, Mexico between 1995-1996. In the study, maize yield (kg / ha) from conventional practices were compared to those under conservation tillage (with 2 Mg / ha as residue mulch). The comparisons were done under two rainfall regimes as shown in Table 2.1-1. The difference in yield was more remarkable in the marginal rainfall zone, where the grain yield from CA is 930 kg / ha.

Table 2.1-1 : Yield Comparison under Different Tillage Systems In Jalisco.

Rainfall Regime	Rainfall Range (mm/annum)	Maize Yield (Kg / ha)		Yield Gain from CA (%)
		Conventional Tillage (CT)	Conservation Tillage (CA) (with 2 Mg / ha residue mulch)	(CA-CT)/CT*100
Favorable	600-800	5590	5730	2.5
Marginal	400-600	1250	2180	74.7

Source : Erenstein, (2003)

A cost benefit analysis was done by Mwalley and Rockström, (2003) to establish the gross margins and net farm income of conservation agriculture in semi-arid Arusha and Arumeru districts in Tanzania. This analysis (Table 2.1-2) showed that the conventional farmer practice was giving an average grain yield of 3.5 t/ha and a net income of -11936 Tanzania Shillings, which was approximately 12 US Dollars at the time of the study (1998 – 2002).

It is interesting to note that even though the difference in grain yield may appear marginal at face value, i.e. 1.25 t/ha (Table 2.1-2); the difference in net income is rather high. The conventional farmer practice has a negative gross margin, leading to a negative net income and a rather high total variable cost.

Table 2.1-2 : Cost Benefit Analysis of CA in Tanzania

Item	Costs in Tanzania Shillings (1000 TSh = 1US$)		
	Conventional (CT) (3.5 t/ha)	**Conservation Farming (CF) (4.75 t/ha)**	**Variance (CF – CT) (1.25 t/ha)**
Gross Output	69564	96843	27279
Total Variable Costs	79000	76000	-3000
Gross Margin	-9436	20843	30279
Total Fixed Costs	2500	3000	500
Net Farm Income	**-11936**	**17843**	**29799**

Source: Mwalley and Rockström, (2003)

2.1.3 Challenges of Conservation Agriculture

The biggest challenge with conservation agriculture, according to Giller *et al.,* (2009) is that it demands a complete change of mind set. CA requires that the farmers adopt all the three principles at once and simultaneously. The farmer has to change their entire agricultural production system. This may at times mean even adjusting social lifestyles; for example to gain more labour for weeding in the early years of adoption. The arguments are centered on the notion that unless all the three principles are embraced simultaneously, a farmer may not get the maximum benefits from the technology (Giller *et al.,* 2009).

As it is the case with most land management technologies, the full benefits of adopting CA only becomes significant after the 5th year. There are even documentations of depressed yields in the early years of adoption (Giller *et al.,* 2009). This becomes a challenge for the smallholder farmer who would adopt the technology with the hope of raising their yields from the typical 1 ton / ha to the acclaimed potential of 6 ton / ha (Falkenmark *et al.,* 2004).

Vigorous weed control in the early years of CA to reduce weed populations over time is another challenge. Various herbicides are available on the market that reduces the comparative costs for weeding. The smallholder farmer however has not been able to afford such herbicides, hence maintains manual weeding (Giller *et al.,* 2009, Mwalley and Rockström, 2003). The increased frequency of weeding may be a challenge for the majority of smallholder farmers, who hardly ever have enough labour at their disposal.

Mulching is one key technique in CA, promoted to improve the soil organic matter content; improve soil structure; and protect the soil from extreme temperatures and raindrop impact. In smallholder farming mulching is another challenge. Mulching is traditionally done with crop residues; which in many communities have competing uses such as livestock feed and fuel wood (Giller *et al.*, 2009). Generally even where the crop residues are available, they are hardly enough to meet the required mulching thresholds due to low biomass production (Falkenmark and Rockström, 2004; Mwalley and Rockström, 2003).

Rippers and sub-soilers have become some of the simplest implements to fit into the smallholder faming community. Efforts have been made, e.g. in Kenya, to train local artisan to either produce prototypes or modify already existing ploughs (Kaumbutho *et al*., 2008; Mwalley and Rockström, 2003). These implements are not yet readily available and affordable to the majority of smallholder farmers (Mwalley and Rockström, 2003).

2.2 Seasonal Rainfall

The larger part of the Southern African region is subject to climatic extremes that often result in poor crop yields. Maize is the most important crop grown in this region and is mostly rain fed (Martin *et al*., 2000). A strong dependence upon rain fed agriculture, high population growth rates, and unstable economic conditions compound the sensitivity, particularly of smallholder farmers, to climatic extremes such as droughts and floods (Rockström, *et al.*, 2003). To understand the effects of such extreme climatic events, models have been developed such as the maize water-stress model. This model relates the crop water requirements and percent yield reduction that results from sub optimal rainfall conditions (Martin, *et al.*, 2000).

Farmers in developing countries have the potential to benefit significantly from weather and climate forecasts; which can reduce their level of vulnerability to extreme weather events (Stone *et al.*, 2006). Appropriate interpretation of the forecasts however would be key. This entails an interpretation into a language that farmers and extension workers understand; and provides them with options for decision making.

A study by Chibulu, (2007) for instance revealed that temporal variation of rainfall was significant in the long term but insignificant in the short term. Chibulu also observed that spatial variation was significant in the short term, but not significant enough to cause any differences in yield. In the study by Chibulu (2007), the farmers interviewed regarded the amount of rainfall, and its variability as the most limiting factor to crop production; followed by soil fertility and unavailability of recommended varieties in the area. Chibulu also argues that even though farmers admit the presence of rainfall variability in the area, they continue to grow maize, despite the fact that the rainfall received in the area has become lower than the average rainfall required to support maize production.

Stone and Meinke, (2006) argue that while the value of forecasts to farmers will depend on their accuracy, it is necessary to identify those areas where tactical changes can be made either to take advantage of predicted (probabilistic) above-average rainfall or to reduce losses in predicted (probabilistic) below-average situations. While farmers are interested in receiving seasonal rainfall forecasts that provide the probability of receiving a normal rainfall, they are much more interested in receiving forecasts that are more relevant to their actual decisions. This, for instance, could include the commencement and cessation of the wet season; or whether there would be interruptions in rains. As was in the study by Chibulu (2007), the farmers in that study area could, for instance, adapt to crops that would be in synchrony with the observed seasonal rainfall variability patterns.

2.2.1 The Water Requirement Satisfaction Index

The Water Requirement Satisfaction Index (WRSI) is a water balance indicator that relates seasonal rainfall forecasts and crop yields (Mukhala and Hoefsloot, 2004). The model breaks an entire rainy season into ten (10) day periods, called dekads. A crop is traced through its entire growing cycle (initial, vegetative, flowering, and ripening) to assess how the crop water requirement (CWR) for each stage was satisfied by the rain falling in that dekad. This assessment is then computed into the Water Requirement Satisfaction Index. The final WRSI is an average of the crop water requirement for the dekads covering the length of a growing season of a given crop (Martin *et al.*, 2000; Mukhala and Hoefsloot, 2004). The WRSI is computed from equation 1 (Mukhala and Hoefsloot, 2004):

WRSI = (AET / WR) * 100……………………………….Equation 1

Where

WRSI	:	Water Requirement Satisfaction Index (%)
AET	:	Actual Evapotranspiration (mm/day)
WR	:	Crop Water Requirement (mm/day)

The interpretation of the WRSI is linked to crop performance (Table 2.2-1). As the WRSI approaches 100, crop performance is expected to be very good and a farmer is expected to get over 100% yield of the maximum potential yield. When the WRSI is below 50, crop performance is expected to be a “complete failure” and yield is expected to be less than 10% of its potential (Martin *et al*., 2000).

The WRSI can either be computed for crops under rain fed or irrigated agriculture (Martin *et al*., 2000). The ultimate interpretation however remains that as the WRSI approaches 100, crop performance should be approaching 100% of its potential. This implies that under whatever technology a crop is, yield should follow the interpretation of the index. A relationship can thus be established between the WRSI and conservation agriculture. The hypothesis from the interpretation of the WRSI is that the average maize grain yield will increase with an increase in the index. The second hypothesis is that grain yield from conservation agriculture should be significantly higher when compared to that from conventional farmer’s practice. It then follows that the higher the WRSI the greater the yield gains to be obtained from CA.

Table 2.2-1: Interpretation of the Water Requirement Satisfaction Index

WRSI	Classification of Crop Performance	Expected Percentage of Maximum Potential Yield
100	Very good	>100
95–99	Good	90–100
80–94	Average	50–90
60–79	Mediocre	20–50
50–59	Poor	10–20
<50	Complete failure	<10

Source: FAO, 1986

2.2.2 The Water Requirement Satisfaction Index and the AgroMetShell

The Water Requirement Satisfaction Index can be computed using the AgroMetShell (AMS) (Mukhala and Hoefsloot, 2004). The AMS is a crop specific water balancing software whose primary uses are agro-meteorological crop modeling and yield forecasting. It was specifically developed as a tool box for early warning purposes; and has been built up from the FAOINDEX, which was a model for relating yield responses to water stress (Mukhala and Hoefsloot, 2004).

To derive its functions the AMS is operated in two modes, (1) monitoring mode or (2) in risk analysis mode. The monitoring mode is an analysis of one growing season covering many stations in a specific area, usually a country or a province in a country. This would be performed from the beginning of the growing season until harvest time. It is in this monitoring mode that the yield prediction is done (Mukhala and Hoefsloot, 2004).

The second mode (risk analysis) covers a similar analysis as in the monitoring mode but for one station only, and over many years. This provides the agronomist with some information indicating whether a particular crop should actually be grown in that particular area or not. The output of a risk analysis shows how many years or seasons the water requirements of a particular crop were satisfied or have been beyond a certain threshold value.

Inputs to the AMS water balance model include meteorological parameters namely actual and long-term average rainfall; actual and long-term average potential evapotranspiration (PET), (normal in this case is the long term average), the type of crop for which water balance is being calculated, percentage of effective rainfall (as a function of the terrain and type of soil); planting dekads (start of the season); soil water holding capacity; the length of the growing period (LGP); crop coefficient and irrigation amounts where applicable. The WRSI gets to be one of the outputs computed with these inputs (Mukhala and Hoefsloot, 2004).

The AMS, also referred to as the FAO Crop Specific Soil Water Balance model, produces a number of outputs for the various stages in the growth and development of a crop (Mukhala and Hoefsloot, 2004). The water balance variables that are produced include, excess soil water; actual evapo-transpiration; soil water deficit over the initial, vegetative, flowering and ripening phase. Other outputs include total water requirement; the water requirement satisfaction index at the time of monitoring as well as at the end of the growing season (Mukhala and Hoefsloot, 2004).

These outputs are used in further computations and statistical analyses to come up with decisions for crop modeling and yield forecasting. A study by Boyce (2005) confirmed the potential use of the AMS as a toolbox for maize yield forecasting and estimation in Malawi. The WRSI was singled out among the many outputs of the AMS and attempts were made to see if it can be used to advise suitability of conservation agriculture in a given area.

One of the functions of the WRSI is to inform if a crop should be ordinarily grown in a particular area. This is achieved by looking at how many seasons the crop water requirement was satisfied, over a specified period of time, in a specific area. In this case, the location and the crop are held constant, while one observes the crop water requirement satisfaction in that one area over many years.

Apart from observing the crop water requirement over time, it observes if conservation agriculture significantly contributes to the satisfaction of the crop water requirement of maize, at a given location over many years. This attempts to see if the Water Requirement Satisfaction Index can be used to indicate suitability of the CA technology in a particular area.

CHAPTER THREE

3 RESEARCH METHODS AND MATERIALS

3.1 Districts under study

This study involved a sample of small scale farmers from 6 districts spread in the central region of Malawi (Figure 3.1-1). The 6 districts are Balaka, Dowa, Machinga, Zomba, Salima and Nkhotakota.

The districts are in three Agricultural Development Divisions (ADD): Machinga (Balaka and Machinga); Salima (Salima and Nkhotakota); and Kasungu (Dowa). ADDs are administrative areas for agriculture extension; demarcated based on agro-ecological zones.

The three districts are in three climatological zones : Central (Dowa); Lakeshore (Salima and Nkhotakota); Southern (Zomba and Machinga). There is some overlapping on zoning, largely because the major differentiating factor between agro-ecological zone and climatological zone is soil, which is not present in the latter (Boyce, 2005).

The agriculture administrative system is further divided into lower level administration namely Extension Planning Area. The farmers in this study come from the following EPAs: Toleza in Balaka district; Mvera in Dowa district; Ntubwi in Machinga district; Zidyana and Mwansambo in Nkhotakota districts; Chinguluwe in Salima district; and Chingale and Malosa in Zomba district.

3.2 Sample of Farmers

Since the study required historical data to establish the relationship between maize yield under conservation agriculture and rainfall season quality, yield data from 34 out 56 farmers was used, as well their corresponding rainfall records.

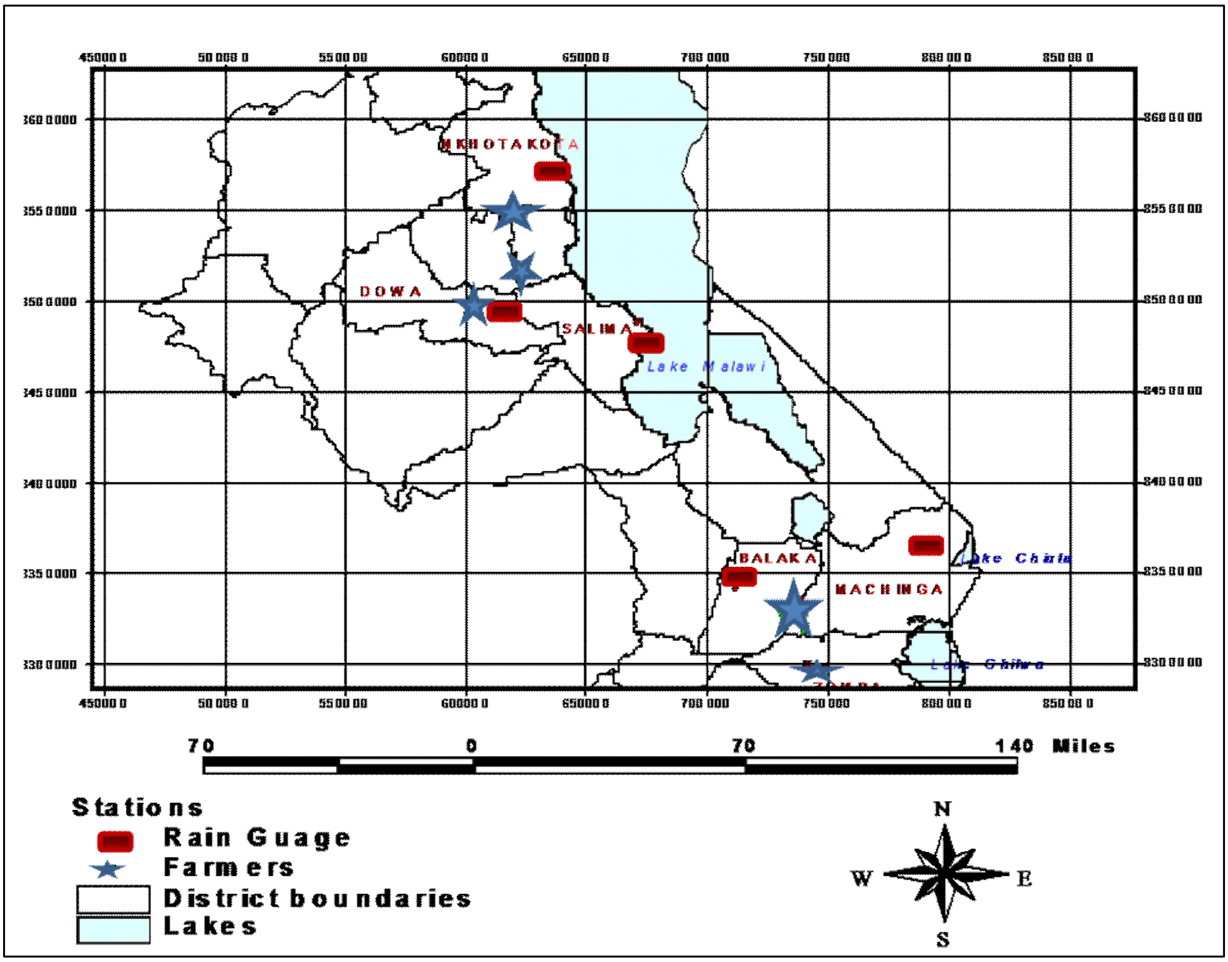


Figure 3.2-1: Locations of Study Districts and Study Sites.

The farmers did not have rainfall records per se. rather the rainfall records were accessed from the Department of Meteorology as well as from NOAA satellite. The farmers under study were 60% of the total sample size, and were chosen based on the agro-ecological zone in which they fall. These 34 farmers were in different years of practicing conservation agriculture ranging from 3 to 4. Table 3.2-1 is a summary of the study districts and the number of farmers involved.

Table 3.2-1 : Numbers of Farmers Involved in the Study

District	Number of Farmers in a Season				
	2005	2006	2007	2008	2009
Balaka	3	4	8	10	9
Dowa	0	4	14	6	5
Machinga	0	0	5	6	6
Nkhotakota	0	7	7	8	7
Salima	0	0	0	0	6
Zomba	0	0	0	8	0
Totals/season	**3**	**15**	**34**	**33**	**33**

The 34 farmers were also sampled due to them having relatively consistent data on yield. There were incidences where a farmer was in year 4 of CA but their records were only present for one year. The study thus had to screen for such anomalies, except for Zomba and Salima whose farmers had yield records only for one year.

3.3 Field Management

The 34 farmers sampled for this study are those that have been under the technical support of the Centre for Improvement of Tropical Maize and Millet (CIMMYT) in collaboration with Total Land Care and the Challenge Program. Each farmer has 3 plots whose treatments are described in Table 3.3-1.

The farmers in the study area identify their treatments as plot 1, 2 and 3 to represent farmers check; CA plus maize; and CA plus maize plus herbicide respectively. The current discussion however identifies plot 1 as farmers check; plot 2 as reduced tillage and plot 3 as conservation agriculture. This naming has been chosen in line with the three principles of conservation agriculture. Plot 3 follows all the three principles hence can be said to have the full CA package. Plot 2 only follows minimum soil disturbance and maximum soil cover, which has been defined as reduced tillage (Langmead, 2005).

Table 3.3-1 : Description of Field Management Practices

Plot No.	Description	Treatment
Plot 1 : Farmers Check	This plot simulates typical smallholder farmers practices. The most profound aspect is that ridges are made every year, which is the traditional practice in Malawi. There is no prescribed practice, with large degree of variability from farmer to farmer. Each farmer chooses how to manage this plot. The farmer follows the traditional practice of making fresh ridges every year; which leads to a great degree of soil disturbance. Maize is planted at 3 seeds per plot at 75 cm spacing between stations, and 90 cm between ridges. The seed can be local seed or hybrid depending on what is available. Weeding done depending on availability of labour and time; and is done with a hoe. Fertilizer applied depending on availability. It is the last plot to be attended to for planting, weeding, and harvesting as priority is given to the other two plots. Except when inputs for the other plots are accessed late it get to be attended early. Generally each of the 3 plots is supposed to be 0.1ha. Farmers tend to deviate from this measurement. This in turn affects availability of inputs particularly fertilizer and seed. When the plots are bigger, most of the inputs meant for this plot are diverted to the other two plots. This plot referred to as the farmers check.	1
Plot 2 : CA+Maize	To ensure minimum soil disturbance, planting is done on old ridges spaced at 75 cm apart, while the plant spacing is at 25 cm with one seed per station. The ridges are made following a geographical contour and are only made in year one of adopting CA. Maize stover is applied on the surface either immediately after harvest or a few months before planting. This is done for the principle of maximum soil cover. Bullet is applied as a pre-planting herbicide at a rate of 4 L/ha. Round Up is applied as a post emergent herbicide at a rate of 4 L /ha. Herbicide application is done as part of minimum soil disturbance. This plot is referred to as reduced tillage.	2
Plot 3: CA+ Maize+ cow peas	The treatments in this plot are similar to plot 2. A legume (mostly pigeon peas) is the added component to this plot. It is planted two weeks after planting the maize. The legume is planted to satisfy the principle of crop rotations and mixtures. This plot is referred to as conservation agriculture.	3

Source :A. Chiwayula, Personal Communication, 2010.

3.4 Data Collection and Analysis

Yield Data

The study used maize yield data from a total of 34 out of 56 farmers spread across 6 districts for up to five (5) growing seasons from 2005 to 2009. The 34 farmers were selected on the basis that they had practiced CA for atleast 3 seasons and had reasonably consistent yield data. The farmers in Zomba and Salima were included in this study even though they only had data for one year according to the data records accessed. This was so to expand the rainfall zone, but also because it was verified that they had practiced CA for 3 years.

The yield data for the farmers was obtained from the International Maize and Wheat Improvement Centre (CIMMYT -Harare Office). CIMMYT has been running on farm trials on various aspects of conservation agriculture in collaboration Total Land Care (a local non governmental organization) and The Challenge Programme. The 34 farmers in this case are the trial farmers.

The members of staff for The Challenge Program and Total Land Care are responsible for the management of the CA projects. CIMMYT compiles general socio-economic and agronomic data from what are called trial and demonstration farmers. The data dates as far back as 2005, where yield data is separated for each of the 3 plots as described in Table 3.3-1.

To meet the objectives of this study, yield data was extracted from the records kept by CIMMYT, for a total of 34 trial and demonstration farmers. These farmers were selected on the basis of agro-ecological zone, climatological zone and years of practicing CA. A total of 15 farmers were sampled for verification of records of the yield data.

Rainfall data

The rainfall data used in this study was from two sources. Historical records from 1970 to 2009 were obtained from the Department of Climate Change and Meteorological Services of the Malawi Government. This comprised of rainfall compiled from rain gauges.

The second data set was rainfall estimates extracted from National Oceanic and Atmospheric Administration (NOAA) satellite images. The NOAA satellite takes images of the entire earth at a 7km resolution every 10 days. This image captures a number of aspects one of which is rainfall. The images come in ASCII format and the rainfall can be extracted using various programs including the AgrometShell (Mukhala and Hoefsloot, 2004). The SADC Regional Remote Sensing Unit distributes these satellite images as country windows. The NOAA rainfall estimates were used to derive point rainfall for each of the plots for the 34 farmers, from 2005 to 2009.

Soil data

The soil sampling was done to establish if there are any improvements in the general aggregate structure on the CA plots compared with non CA plots. Comparisons were made between the bulk density and field capacities of the plots with conservation agriculture and the plots without conservation agriculture.

Two core soil samples were collected per plot; one at depth 0 - 20cm (plough layer). Another two disturbed soil samples were also collected at the same depth. These samples were used for the determination of bulk density (BD, g m^{-3}), Soil texture (percentage clay, silt) and field capacity (%). The sampling was done once in February 2010.

3.5 Computation of the Water Requirement Satisfaction Index

The Water Requirement Satisfaction Index in this study was computed using the AgroMetShell (AMS). The WRSI was computed within the monitoring mode of the AMS. The monitoring mode analyses one growing season covering many stations, and is used for yield forecasting.

Each of the growing seasons from 1970 to 2009 was computed independently. The output for each year is the WRSI for each of the 6 districts. In other words, there were a total of 40 indices for every district over the 40 year period.

Yield forecasting for early warning is done at administrative level, e.g. a country level, which may be further subdivided into smaller units. The decisions made for early warning in Malawi, for example, uses a district as the smallest administrative unit. Each administrative area has its own *coefficient* for the relationship between historical yields and the WRSI. These predictions are done before the end of the harvest season to allow early planning for any deficits. The WRSI reading used in such predictions corresponds to the stage at which the crop is. For example if the prediction was done at flowering stage, the crop water requirement would have been calculated up to this stage; using the actual rain received thus far (Mukhala *et al.*, 2004).

In this study, the WRSI was calculated up to the end of the growing season, using the actual rainfall received. The index at harvest was then linked to the forecasted crop performances, as per the interpretation in Table 2.2-1. The word "prediction" has been used to mean the expected crop performance. If the index is 100, crop performance is classified as very good, and yield predicted to be 100% of its potential.

Inputs to the AMS in this study were

- Actual and long term average decadal rainfall.
- The type of crop in this case hybrid maize.
- Planting dekads (start of the season) which were calculated by the AMS itself based on the Rangeland Index (RI). The RI is used where the actual planting dates are not available (Mukhala and Hoefsloot, 2004).
- The length of the growing period of the maize crop in dekads.

- Crop coefficient for maize.
- Actual and long term average potential evapo-transpiration.

3.6 Data Analysis

Statistical Analysis

The Ordinary Least Square method was used to show effects of several independent variables on the dependent variable. The independent variable in this case being yield; while the dependent variables are rainfall, plot treatment, district, Water Requirement Satisfaction Index and harvest year. The analyses were performed using Stata (version 9.0, Statcorp, USA).

The following General Linear Model was the basis for analysis:

$$\mathbf{Y_{ij} = P_j + D_{ij} + I_{ij} + HY_i + E_{ij}} \text{..} \textbf{Equation 2}$$

Where

Y_{ij}	=	yield of plot i in year j
P_j	=	plot number for year j
D_{ij}	=	district with plot i in year j
I_{ij}	=	Water Requirement Satisfaction Index for plot i in year j
HY_i	=	harvest year for plot j
E_{ij}	=	the error factor for plot i in year j.

All analyses were done at 95% confidence level where $P \leq 0.05$. This means that any analysis whose P value was less than or equal to 0.05 was considered to be statistically significant, and those with p value above 0.05 were not statistical significant.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Characterizing of the Rainfall Seasons

4.1.1 Rainfall Patterns

A simple rainfall analysis was done for the 6 districts to establish general rainfall trends. The fist analysis looked at the onset and cessation of rains in each of the six districts. The counting is based on dekads, an element which was used during the rest of the analysis. A dekad in this case refers to a ten day period. Each calendar year is divided into 36 dekads where dekad one covers the first ten days of the month of January and dekad 36 covers the last ten days of December. The general trend shows that rainfall in all the districts covers 27 dekads, where the first rains start in the 28th dekad of one calendar year; and tail off in the 11th dekad of the next calendar year.

The average annual rainfall (figure 4.1-1) across the six districts ranges from 600 mm to 2000 mm/annum, with 60% of the analysed rainfall during the 40 years exceeding 800 mm/annum. The 1994/95 season had the lowest average annual rainfall in all the six districts, with an average as low as 320 mm. The highest rainfall recorded was above 8000 mm/annum which occurred in Balaka.

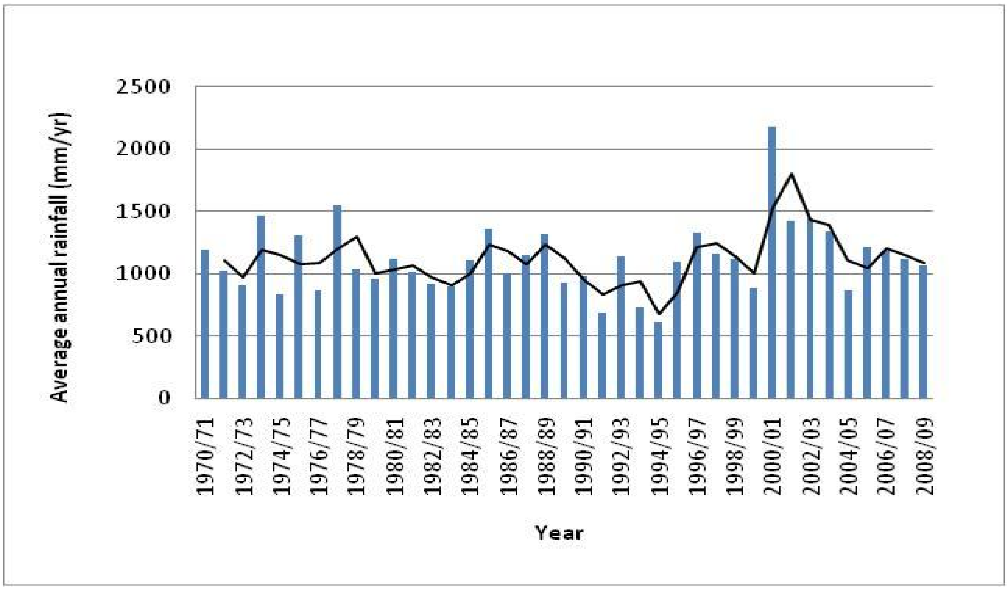


Figure 4.1-1 : Rainfall pattern in the study area (1970 -2009)

4.1.2 Water Requirement Satisfaction Index Patterns at EPA Level

An analysis of 40 rainfall seasons was done to establish rainfall seasonal quality patterns with regards to the Water Requirement Satisfaction Index (WRSI). Historical rainfall records from 8 weather stations manned by the Department of Climate Change and Meteorological Services were used. The reference stations are : Toleza for farmers in Balaka district; Zomba for farmers in Zomba district; Dowa for farmers in Dowa; Lifuwu for farmers in Salima; Chingale for farmers in Machinga district; and Nkhotakota for farmers in Nkhotakota district. The objective of this analysis was to establish general patterns of the WRSI over the 40 year period.

The results of characterizing the rainfall season quality in the 6 districts shows that 42% of the time the districts had rainfall seasons that were of average quality in the 40 years. Seasons whose quality was to lead to complete crop failure occurred 1% of the time, while those with mediocre and poor quality occurred 6% and 2% respectively. 28% of the time the season quality was good and 21% of the time the rainfall season quality was very good.

At district level (Table 4.1-1), the water requirement satisfaction index showed that in the 40 years, Chingale would have very good crop performances 12 times; Dowa 13 times; Lifuwu had the least frequency of 4 times; Nkhotakota, Toleza and Zomba were expected to have 8, 5 and 7 occurrences of very good crop performance respectively. The farmers living within the radius of these rainfall stations were thus expected to have crop yields approaching 100% of their potential in these rainfall seasons.

The rainfall seasons 1990/91 and 1999/2000 for Chingale and Zomba were expected to have complete failure as they had an index of less than 50. The 1978/79, 1999/2000 seasons for Balaka and Zomba were expected to be of poor crop performance as they had an index within the 50 - 59 range.

Table 4.1-1: Historical WRSI for Reference Stations at 10 year interval

Harvest	Water Requirement Satisfaction Index in a District					
Year	Chingale	Dowa	Lifuwu	Nkhotakota	Toleza	Zomba
2009	76	100	100	97	89	97
1999	99	100	96	99	96	76
1989	72	95	97	98	97	90
1979	72	100	82	99	51	69

An analysis was done to establish the relationship between the average annual rainfall and the WRSI. Figure 4.1-2 gives a summary for all this analysis for all the six districts in the 40 years. It was observed that there was no relationship between the annual rainfall (mm) and the WRSI. A well defined relationship in this case would have been *e.g.* the WRSI decreasing or increasing with the average annual rainfall.

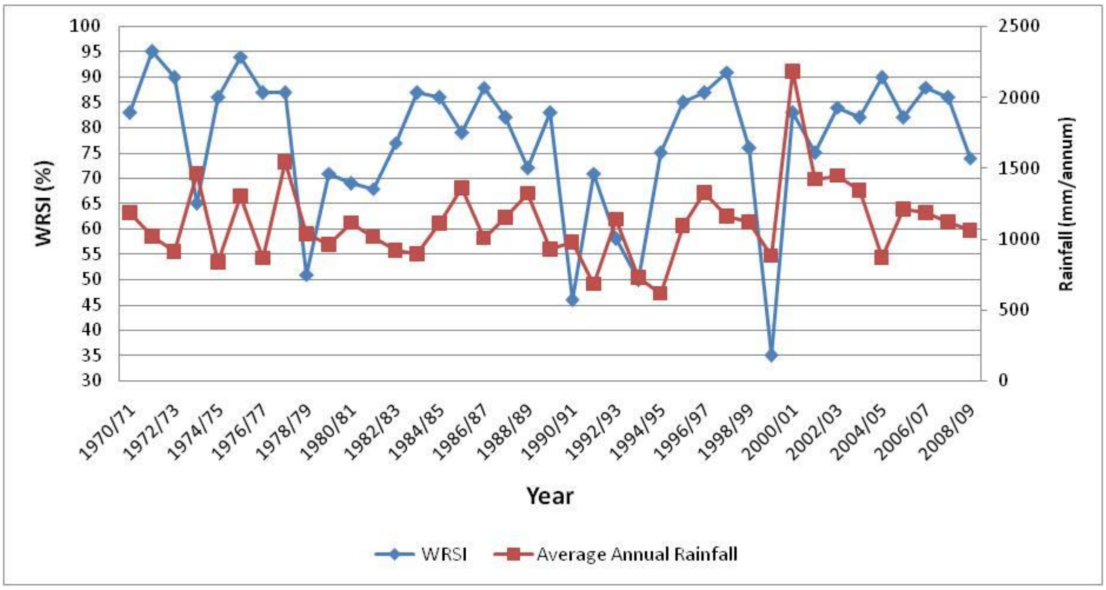


Figure 4.1-2 : Interaction of annual rainfall and WRSI at EPA level .

4.1.3 Water Requirement Satisfaction Index Patterns at Farmer Level

The rainfall seasonal quality for the 34 farmers involved in this study were established. Rainfall estimates from NOAA satelite were used to define seasonal quality for 2005 to 2009 (Table 4.1-1). The WRSI characterised the rainfall seasonal quality for Balaka district as very good for harvest year 2007 whose index reading was 100. This is different from the EPA level characterisation which was characterised good at index 95. Harvest years 2005 and 2006 good rainfall season, with an index of 97. At EPA level, 2005 was very good and 2006 was average at index 82. At both EPA and farmer level, harvest year 2009 had an average rainfall season with an index reading of 89 and 84 respectively.

Table 4.1-2 : Definition of Rainfall Season Quality at Farmer Level

Harvest Year	District	Calculated Water Requirement Satisfaction Index	Definition of Rainfall Season Quality
2005	Balaka	97	Good
2006	Balaka	97	Good
2006	Dowa	100	Very good
2006	Nkhotakota	100	Very good
2007	Balaka	100	Very good
2007	Dowa	97	Good
2007	Machinga	100	Very good
2007	Nkhotakota	97	Good
2008	Balaka	97	Good
2008	Dowa	100	Very good
2008	Machinga	96	Good
2008	Nkhotakota	100	Very good
2008	Zomba	86	Average
2009	Balaka	84	Average
2009	Dowa	99	Good
2009	Machinga	88	Average
2009	Nkhotakota	97	Good
2009	Salima	100	Very good

Dowa district had 2 occurences of very good rainfall seasons, occuring in 2006 and 2008 at farmer level. At EPA this was only true for 2008. The rainfall season for 2006 was to be good season. Rainfall seasons 2007 and 2009 were to be good at farmer level. At EPA level, 2007 was to be a good season while 2009 was to be a very good season.

Machinga district had 1 occurrence of a very good season in the 5 years under study, occuring in 2007. This occurrence was both at EPA and farmer level. The quality of the 2008 season was good at farmer level and very good at EPA level. While the seasonal quality for 2009 was average for farmer level and mediocre at EPA level.

In Nkhotakota district, the rainfall season for 2006 was characterised as very good at farmer level, while at EPA it was good. The rainfall seasonal quality for 2007 was good at both EPA and farmer level. The rainfall for 2008 was very good at farmer level while it was good at EPA level. 2009 had good rainfall season at both EPA and farmer level. Salima district had a very good season at both EPA and farmer level. while Zomba district had an average rainfall season at farmer level but very good at EPA level.

The ultimate intepretation of the WRSI relates the season quality and yield that a farmer gets in that season. The characterisations done at EPA and farmer level were thus used to establish relationships with yields obtained at EPA and farmer level. Further more an attempt was made to establish if there are yield differences between conservation agriculture and farmers practice at a given water requirement satisfaction index. This was done by comparing the average grain yield from CA and non CA plots.

Each of the 34 farmers had 3 plots, 2 under CA, and 1 as a control. The computations of the WRSI done at the farmer level revealed that in a given year, the WRSI for the 3 plots would be the same. Further more, for the farmers that were in a cluster, their WRSI in a given year turned out to be similar (Annex 2).

A further assesment was made on the relationship between the rainfall used in computing the WRSI and the WRSI itself (Figure 4.1-3). The WRSI increases with an increase in rainfall and has an R^2 value of 0.9. This strong relationship between the WRSI and rainfall could be explained in that WRSI measures how well the crop water requirement was satisfied. This satisfaction among other factors will be highly inluenced by the amount of water available. Since this discussion focuses on rainfed agriculture, it follows that the amount of rainwater available should determine the level of which crop water requirement will be satisfied.

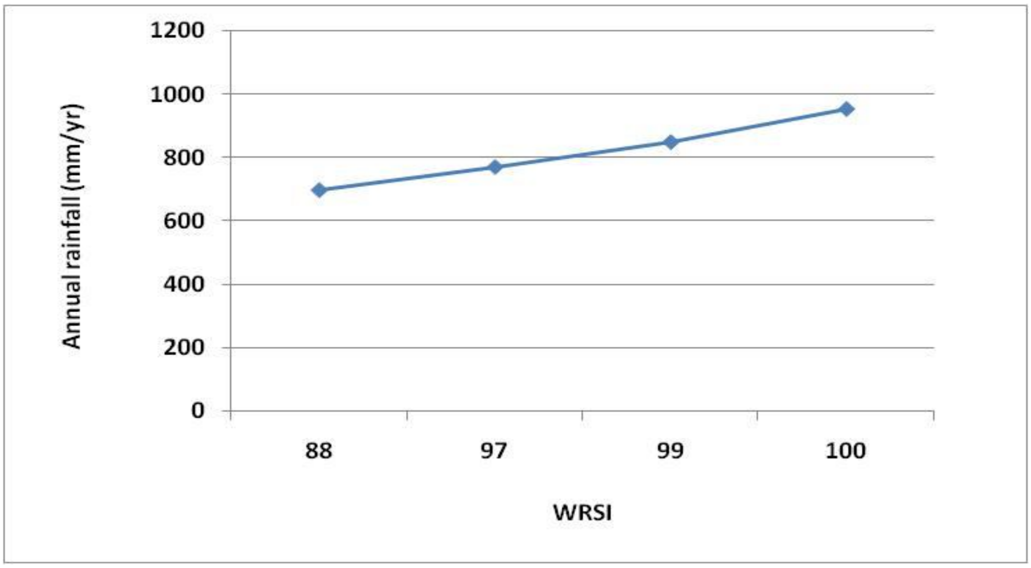


Figure 4.1-3 : The relationship between annual rainfall and the WRSI at farmer level

4.1.4 Summary on Characterizing of the Rainfall Seasons

Over the 40 year period, in 4 out of the 6 districts, rainfall seasonal quality at EPA level would result in above average crop perfromance. This entails that grain yield would be above 50% of its potential for these 4 districts in the 40 year period. The lowest rainfall season quality at farmer level which corresponds to a crop performance of between 90 – 100% yield was still classified as good.

Out of the 18 determinations of the seasonal quality done at farmer level, only 6 matched with the ones at EPA level. One of the reasons for this could be that these two computations used different sources of rainfall.

If this computation was being done for early warnig purposes in the areas where the 34 farmers are located, it would have used the rainfall used for EPA level computation (i.e. the rainfall from the weather stations under the Meteorology Department). The radius of these stations to the nearest farmer range from 10 km – 20km. For purposes of this study, the farmer level computation required point rainfall, hence the use of rainfall estimates from NOAA satelite.

An analysis was therefore done to compare the rainfall estimates from NOAA with the rain gauge recordings that are done by the Meteorology Department. A further analysis was also done to compare these two rainfall recordsings with the long term average rainfall in areas where the 34 farmers are located. The long term average being rainfall that is expected in a normal year. Figure 4.1-4 gives a summary of the relationship between the average rain gauge (recordings from the weather stations) and rainfall estimates (the rainfall figures downloaded from NOAA satelite).

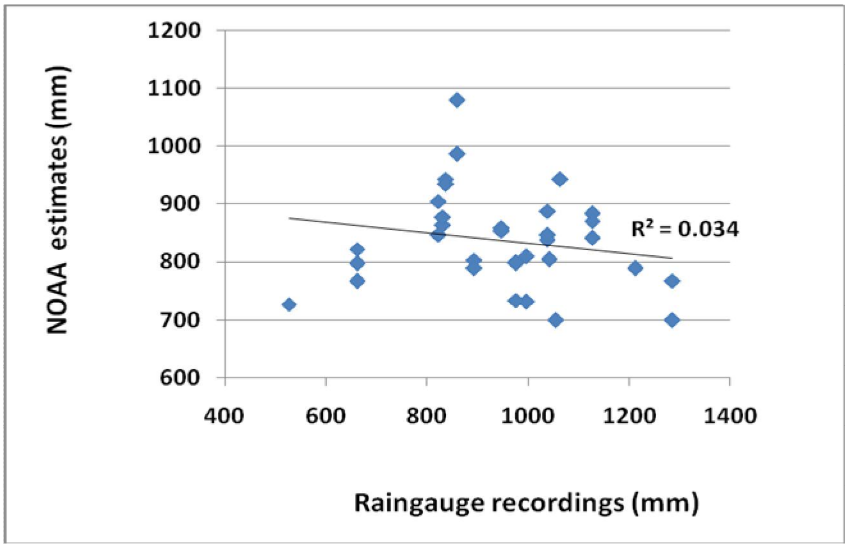


Figure 4.1-4: Comparison of rainfall figures from NOAA satellite and rain gauge readings

A further observation was made at district level. In Balaka district, rainfall estimates from NOAA were not significantly different from the long term average, but they were significantly different from the rain gauge recordings with p=0.000. Long term averages were not significantly different from rain gauge readings.

In Dowa district, rainfall estimates were not significantly different from long term average and rain gauge readings ($p = 0.715$). This was also true for long term average and rain gauge readings. In Machinga district, rainfall estimates were significantly different from long term averages with p=000. But there was no statistical relationship between estimates and rain gauge, and between rain gauge and long term average.

The rainfall estimates for Nkhotakota district were not statistically different from long term average; but they were statistically different from rain gauge readings ($p = 0.000$). Rain gauge readings were not different from long term averages. In Salima district, there was no statistical relationship between the three rainfall values.

The rainfall estimates for Zomba district were statistically different from the long term averages. But there was no statistical relationship between estimates and rain gauge readings and between rain gauge and long term average of 813 mm/annum.

A total of 4 out of the 6 districts had their rainfall estimates from NOAA not statistically different from the normals. It can thus be said that these rainfall estimates were 66% in line with what is expected as the normal rain within the radius of the 34 farmers under this study.

Ideally, the rainfall estimates from NOAA should not have been significantly different from the rain gauge recordings. This would be because they are readings of the same area and the same point. However as figure 4.1-4 shows above, the two readings have no relationship in this case. This implies that they cannot be substituted one for another. Since the two recordings were from different technologies, it is possible one of the technologies did not do correct recordings. As to which technology might not be correct is however beyond the scope of the current study.

4.2 Yield Responses to the Rainfall Seasonal Quality

4.2.1 Average Grain Yield Patterns at EPA Level

An analysis was made on the general grain yield production in the Extension Planning Areas (EPA) for the 34 farmers for the past 25 years. Historical hybrid maize production estimates were obtained for years 1984 to 2009. These records are for smallholder farmers who practice rain fed production.

In this analysis each of the the EPAs are grouped into the districts within which they fall. This entails that the estimates are for a particular EPA (except for Nkhotakota which has 2 EPAs). The use of districts has been used as a unique identifier at country level as well as a grouping factor at the local level. Figure 4.2-1 gives a summary of the average grain yield at the EPA level over the 25 year period. The general trend is that the average yield is increaing with time, with 2009 having the highest yield.

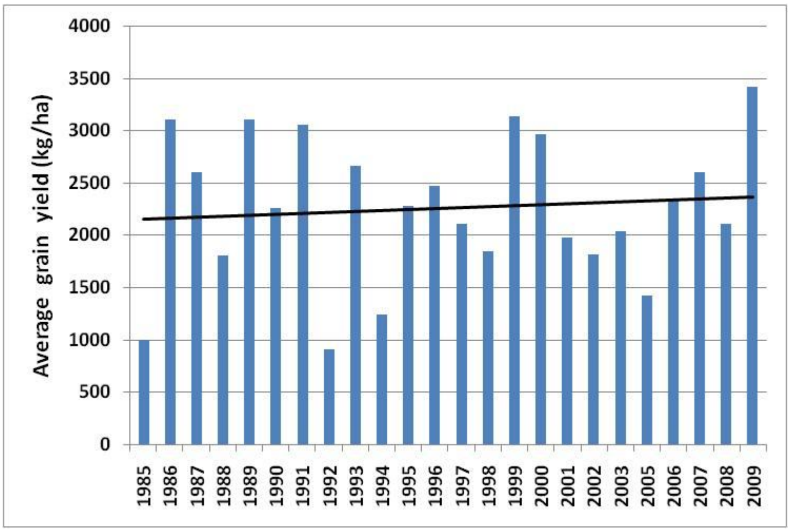


Figure 4.2-1 : Average Grain Yield Over Time at EPA Level

Cumulatively, 1992 had the lowest grain yield of 910 kg / ha. Balaka district had the lowest recorded grain yield of 24 kg / ha; followed by Salima and Dowa which had 700 and 900 kg/ha respectively. Harvest year 1999 had the highest recorded average grain yield of 3970 kg / ha in Salima district.

4.2.2 Average Grain Yield – Annual Rainfall – WRSI Interactions at EPA Level

Regression analyses were run to relate the average grain yield with the WRSI and the average rainfall over time at district level. The objective of these analyses was to determine yield responses to the WRSI. The hypothesis derived from the interpretation of the WRSI was that the average grain yield should increase with an increase in the WRSI.

The first part of the analyses observes the actual yield against the expected grain yield, which in Malawi is expected to be 3000 kg / ha while the potential is 5000 kg / ha, for rain fed maize production under local management (Guide to Agriculture Production 2005). The second part observes crop performance (in terms of obtained grain yields) in relation to the interpretation of the WRSI as in Table 2.2-1. Thirdly an observation is made as to whether the index is a better predictor of crop performance as compared to annual rainfall.

Balaka District

Harvest years 1992, 2001 and 2008 were expected to have very good crop performance as they had an index of 100. The corresponding average grain yield for these seasons are 24, 1993 and 1932 kg/ha respectively. These fall below the general expected average grain yield for hybrids in Malawi. Harvest year 1991 was expected to be a complete crop failure but had an average grain yield of 2200 kg/ha which is higher than that obtained in what was meant to be a very good season. Figure 4.2-2 gives a summary of the relationship of the three parameters.

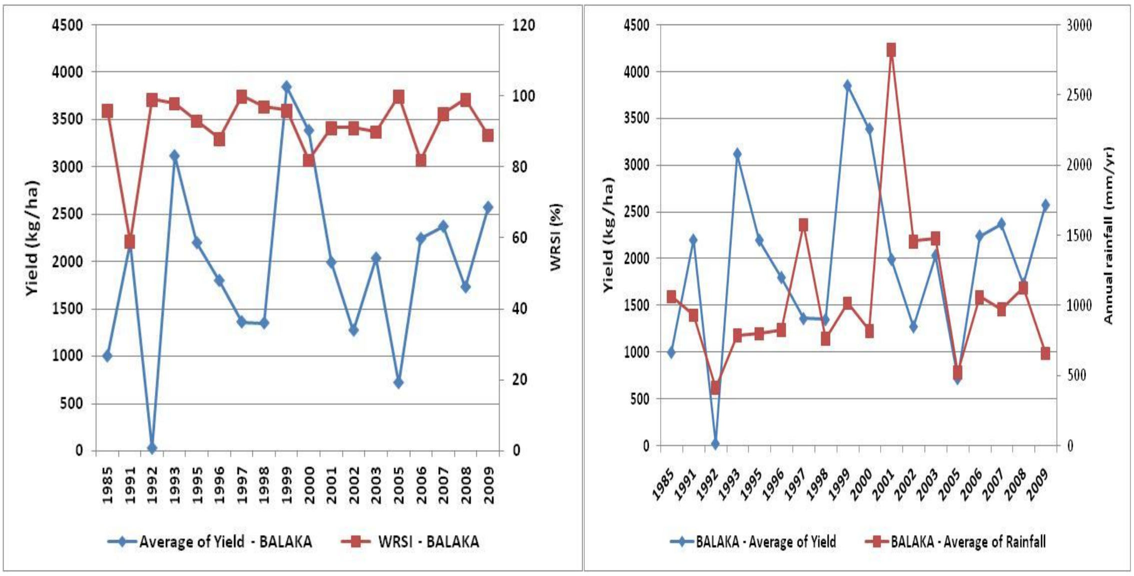


Figure 4.2-2 : Yield - WRSI – Rainfall relationship for Balaka at EPA level.

As the WRSI approaches 100, the average grain yield is decreasing by 28 kg/ha. In contrast, grain yield in increasing with an increase in rainfall. Both the index and rainfall however do not significantly relate to the ultimate yield

Dowa District

The lowest recorded seasons for Dowa district in the 25 years were 1983, 1985 and 1986 whose crop performance was expected to be average. The seasons 1992, 1999, 2008, and 2009 were expected to have very good crop performance and had an average grain yield of 900, 1979, 2155, and 3743 kg /ha respectively. Even though harvest year 2009 had an average grain yield above the expected average yield under local management; it is still significantly lower than the expected maximum potential yield. Figure 4.2-3 summarises the relationships between the three parameters.

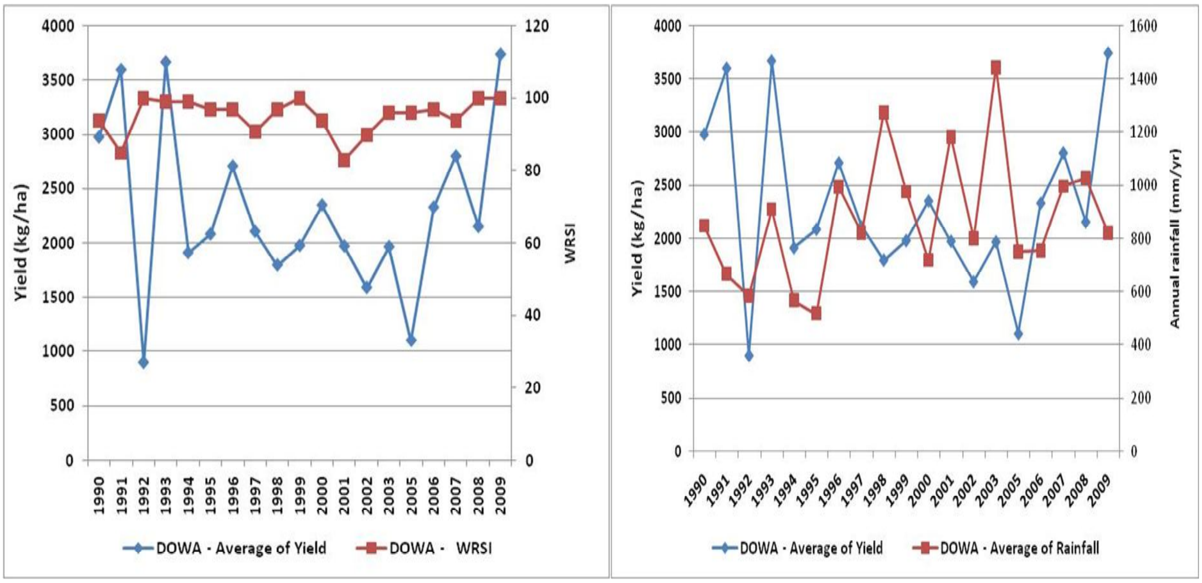


Figure 4.2-3 : Yield - WRSI - Rainfall Relationship for Dowa at EPA level.

The WRSI did not relate with yield in Dowa as per its interpretation. As the index approaches 100, crop performance is decreasing by 14 kg/ha though not significantly. The yield is however increasing with an increase in rainfall, though the increase is not significant.

Machinga District

Harvest year 2009 however was also expected to be a mediocre year and had a grain yield of 3178 kg/ha which is just above the expected grain yield. The harvest years 1990, 1997, 1998, 2002, 2007 and 2008 were expected to have very good crop performance but had average grain yields of 2528, 2100, 1930, 1804, 2895 and 2211 kg/ha respectively.

The average grain yield in Machinga goes against the expectation of the WRSI. The average yield is decreasing by 7 kg with an increase in the index. When compared with annual rainfall, the average grain yield is also decreasing with an increase in rainfall as shown in Figure 4.2-4. Both these decreases are however not statistically significant

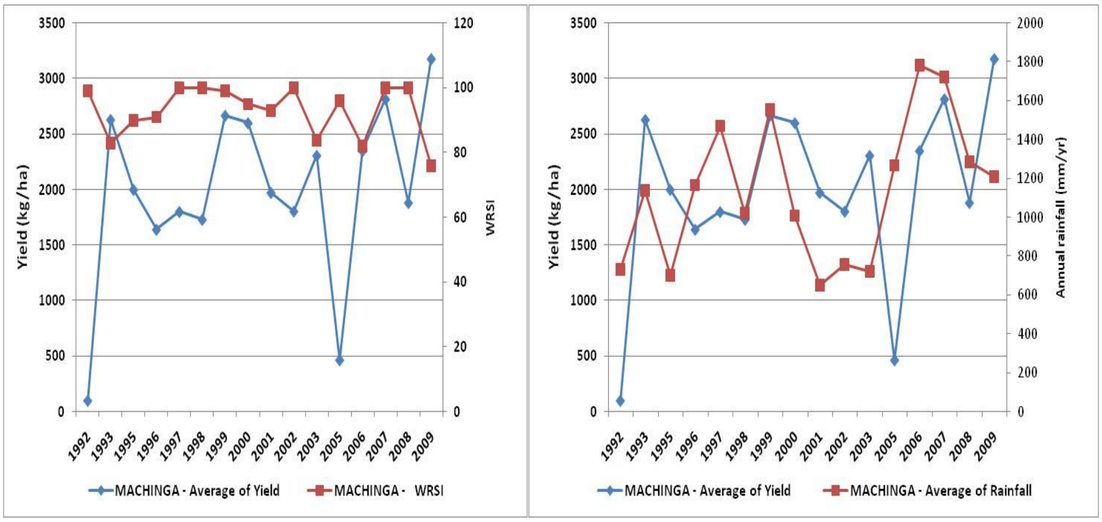


Figure 4.2-4 : Yield – WRSI – Rainfall Relationship for Machinga at EPA level.

Nkhotakota District

The yield data from Nkhotakota district came from two EPAs, and one reference weather station. Nkhotakota had 1991 as the season with the lowest index and crop performance was expected to be mediocre. In this season however average grain yield for Mwansambo was 3500 kg/ha while that of Zidyana was 2500 kg/ha and was statistically not significant. The harvest years 1993 and 1996 were expected to be very good and had average grain yield of 1401 and 2787 kg/ha respectively.

It was observed that the average grain yield for Nkhotakota was decreasing with a unit increase in the WRSI. The yield is however increasing with an increase in rainfall as illustrated in Figure 4.2-5. Both the index and rainfall are not having significant relationship with the average grain yield.

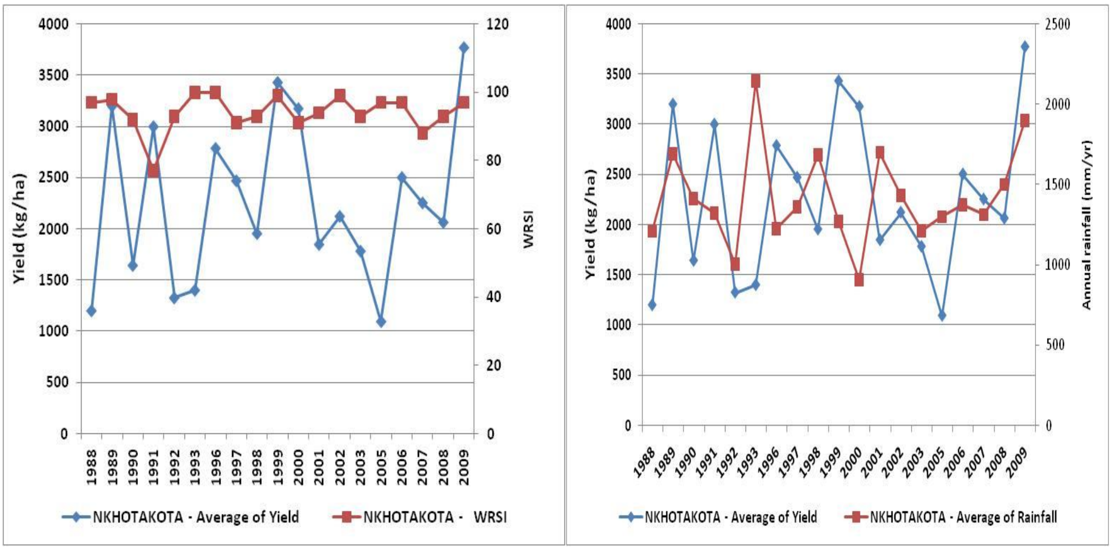


Figure 4.2-5: Yield – WRSI – Rainfall relationship for Nkhotakota at EPA level

Salima District

The crop performance for Salima in 1993 was expected to be "poor" at index 58. But the average yield in this year was 2748 kg/ha. The lowest yield however in the 25 years for Salima was 569 kg/ha which came in harvest year 1994 which was expected to be a mediocre year with an index of 75. Harvest years 1996 and 2003 were expected to have very good crop performance and had average grain yield of 2075 and 2300 kg/ha respectively.

Salima is the only district where the crop performance increases with an increase in the WRSI and the annual rainfall. Even though these increases are not significant, average grain yield increases by 14kg with an increase in the index, and by 0.17kg with an increase in the annual rainfall. Figure 4.2-6 illustrates these relationships.

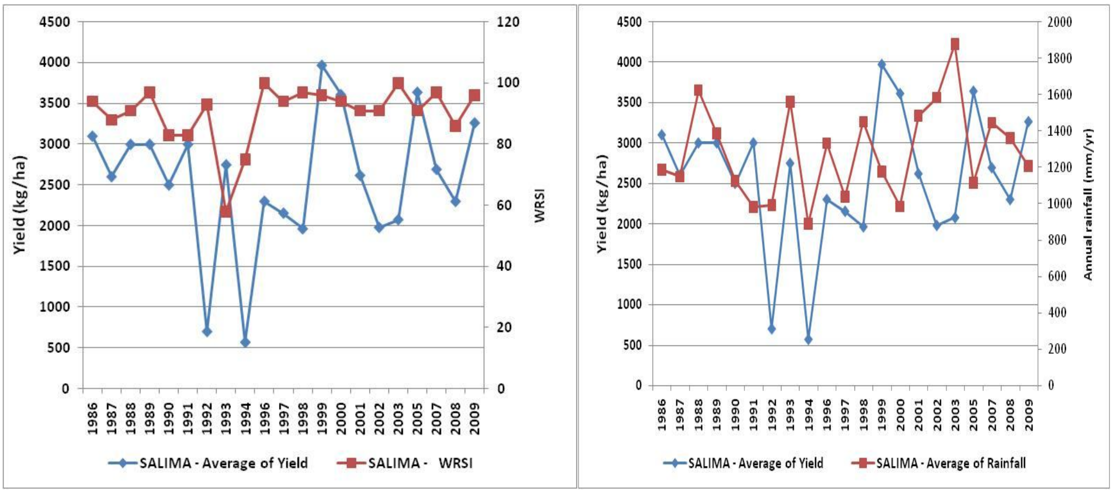


Figure 4.2-6 : Yield – WRSI - Rainfall Relationship for Salima at EPA level.

Zomba District

Harvest years 1992, 1997, 1998, 2002, 2007 were expected to have very good crop performance. Their corresponding average yield were 2528; 2100; 1930; 1804; 2895 and 2211 kg/ha respectively. Just like in Balaka district, these yields fall below the expected minimum yield of hybrid maize under local management. At index 72 crop performance is expected to be at mediocre level yet at this index Zomba had an average grain yield of 3500kg/ha in 1991.

The crop performance in Zomba does not follow the index. As the index approaches 100, crop performance is moving away from 100% of its potential. The same follows for rainfall, the yield is decreasing with an increase in rainfall. This is shown in Figure 4.2-7. Both decreases are not statistically significant.

In summary, out of the crop performances of the 6 districts under study, only Salima district follows the interpretation of the WRSI. In the other 5 districts, crop performance decreases as the index approaches 100. In all the 6 districts, there is no particular trend in the yield, confirming what was said by Gommes, (2001), that average grain yield for maize in most parts of Southern

Africa show no particular trends. Compared with rainfall, in 3 out of 5 districts, crop performance improves with an increase in rainfall. Both the index and rainfall however have been seen not to be statistically significant to explain the crop performance.

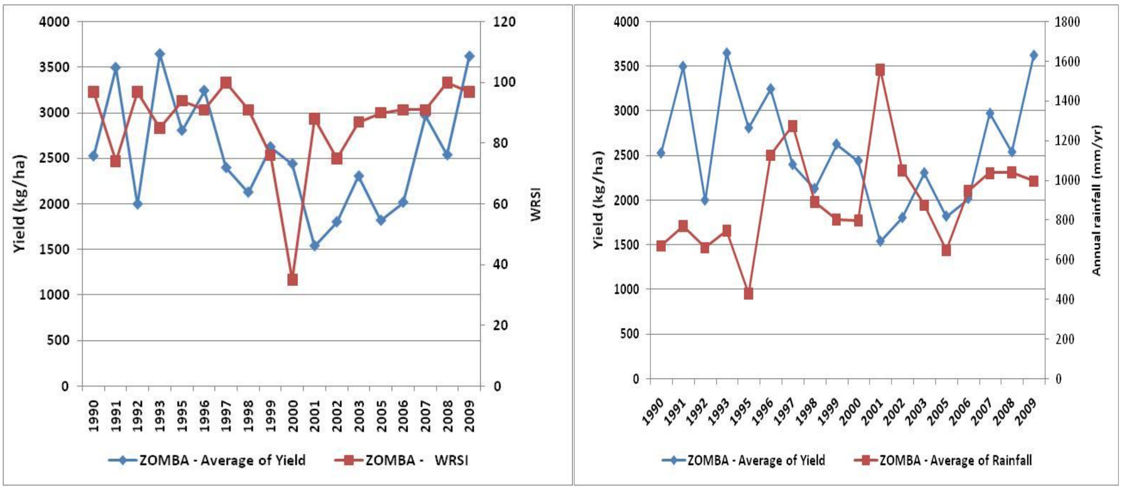


Figure 4.2-7 : Yield -WRSI – Rainfall relationship for Zomba at EPA level

4.2.3 Average Grain Yield – Annual Rainfall – WRSI Interactions at Farmer Level

The relationships between average grain yield (kg/ha), WRSI and annual rainfall (mm) were analysed further at farmer level. An interpretation of the index is made and the corresponding grain yield at a given index compared with what was predicted by the index. In this case, if the index predicts a crop performance of up to 100%, the actual crop yield is evaluated against the prediction.

This comparison uses 3000 kg/ha as the average grain yield a farmer is expected to get from a hybrid maize under local management. While 5000 kg/ha is the potential grain yield a farmer can get from hybrid maize. Local management in this case entails the highest level of management under rain fed, small holder conditions (Guide to Agriculture Production, 2005).

All farmers in a particular district were pulled together, and their cumulative average grain yield analysed over time. In all the districts, the farmers are clustered together in one EPA; except for Nkhotakota and Zomba where the farmers are in two EPAs. These comparisons are from harvest year 2005 to 2009.

Balaka District

Balaka district had farmers spreading across harvest years 2005 to 2009. Harvest year 2005 had 3 farmers, 4 in 2006, 8 in 2007, 10 in 2008 and 9 in 2009. The farmers in 2005 were expected to have two crop performances: others were expected to have very good (>100% of potential) while the second lot good performance (90 – 100% of potential). The crop performance for the farmers predicted to have >100% was 80%, while that predicted to be 90-100 was 43%. The grain yield in this year follows the prediction that crop performance increases with an increase in the index. This prediction however was not statistically significant. In this harvest year, rainfall was also not significant to cause any meaningful changes in the grain yield.

All the 10 farmers in harvest year 2006 were expected to have very good crop performances as they had an index of 100. The average grain yield obtained was 80% of the potential compared to 100% as per predicted by the index. In this season, both the WRSI and annual rainfall did not have any relationship with the yield. The 8 farmers under study in 2007 were expected to have very good crop performance. Their average grain yield was 80% against a prediction of >100%. In this year, the index and annual rainfall did not have any statistical relationship with the yield. But an increase in rainfall would cause a decrease in yield.

The 9 farmers in harvest year 2009 were divided across three predictions: average, good and very good crop performance. The farmers under average who were expected to get 50 -90% got 44% of their potential yield. Farmers under good had 60%, while farmers expected to have >100% had 55% of their potential. In this year, grain yield was increasing with an increase in the index while it decreased with annual rainfall as shown in Figure 4.2-8. Both parameters were not statistically significant in relation to yield.

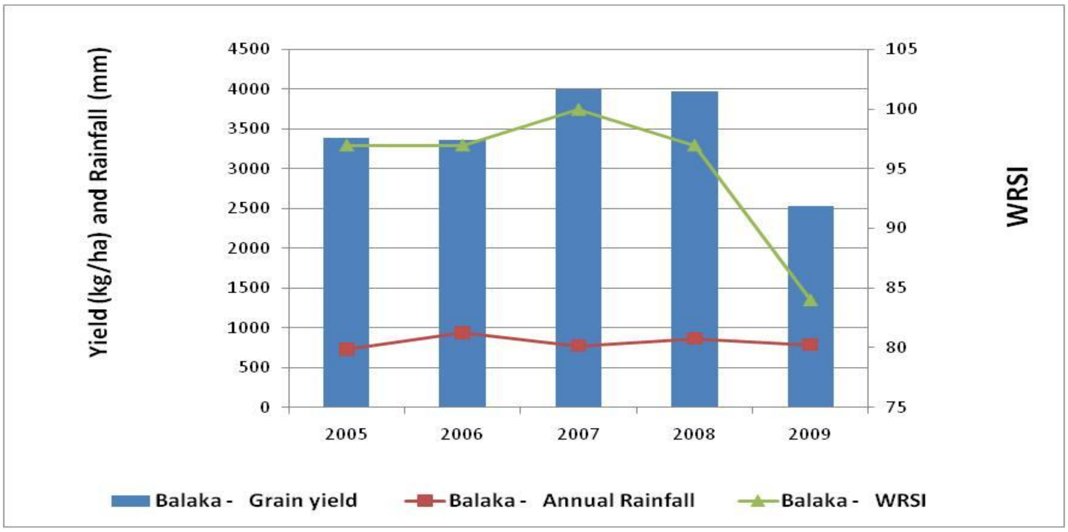


Figure 4.2-8 : Yield -WRSI – Rainfall relationship for Balaka district at farmer level.

Dowa District

Dowa district had farmers spread across harvest years 2006 to 2009. Harvest year 2006 had 4 farmers whose crop performance was expected to be very good. In this year, the average grain yield for the 4 farmers was 84% of its potential compared to a prediction of >100%.

In harvest year 2007, Dowa had 14 farmers, falling either in the very good or good prediction. Those in the very good had 179% of their potential yield which agrees to the >100% prediction. Those farmers at good had grain yields up to 179% of their potential, which was way above the predicted 90-100% of potential. In this year, crop performance was increasing with an increase in the index even though the increase was not statistically significant.

In harvest year 2008, Dowa had 6 farmers, expected to have very good crop performance. The prediction of >100% came to pass as the farmers had up to 105% of their potential. In this year, there was no relationship between the grain yield and the index, and the grain yield and the rainfall.

The harvest year 2009 had 5 farmers, who were split between very good and good predictions. Their corresponding average grain yield was 105% and 88% of their potential. In this season, an increase in the WRSI would increase the grain yield by 844 kg and this increase was statistically significant. Crop performance would also increase with rainfall, but the rainfall was not significantly. Figure 4.2-9 shows the relationship of the 3 parameters.

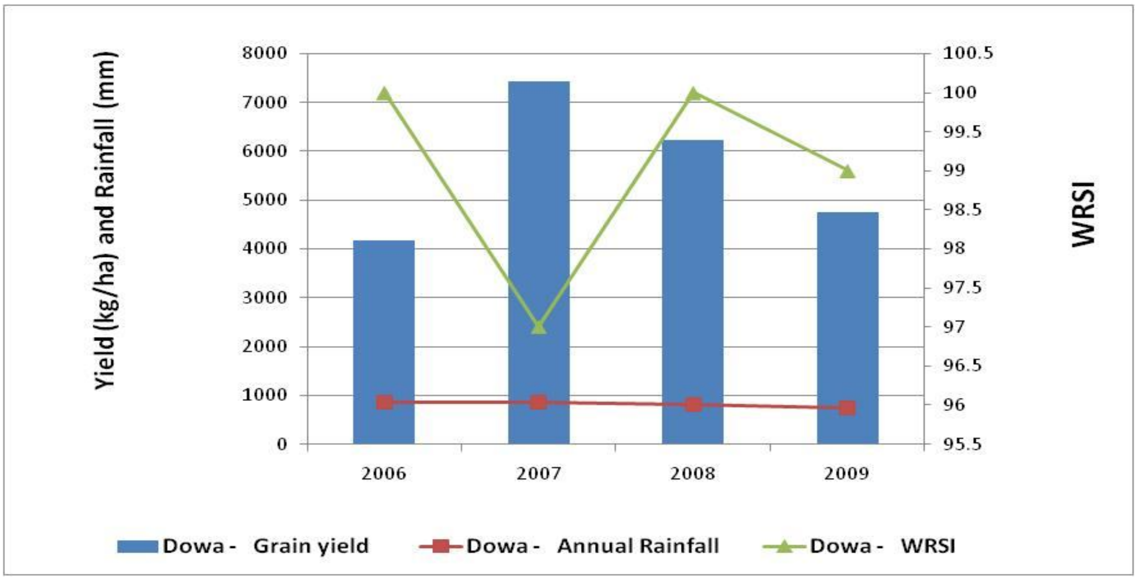


Figure 4.2-9 : Yield -WRSI – Rainfall relationship for Dowa district at farmer level.

Machinga District

Machinga district had farmers from 2007 to 2009. The 5 farmers in 2007 were predicted to have very good crop performance. Their average grain yield however was 79% of its potential against a prediction of >100%. Harvest year 2008 had 6 farmers, predicted to have between 90 to 100% of their potential. The average grain yield however was 116%, slightly higher than the prediction. Harvest year 2009 had 6 farmers, who got 41% of their potential yield against the predicted 90%.

In all the three seasons in Machinga district, there was no relation between the WRSI and the grain yield (Figure 4.2-10). The annual rainfall also did not affect the grain yield statistically.

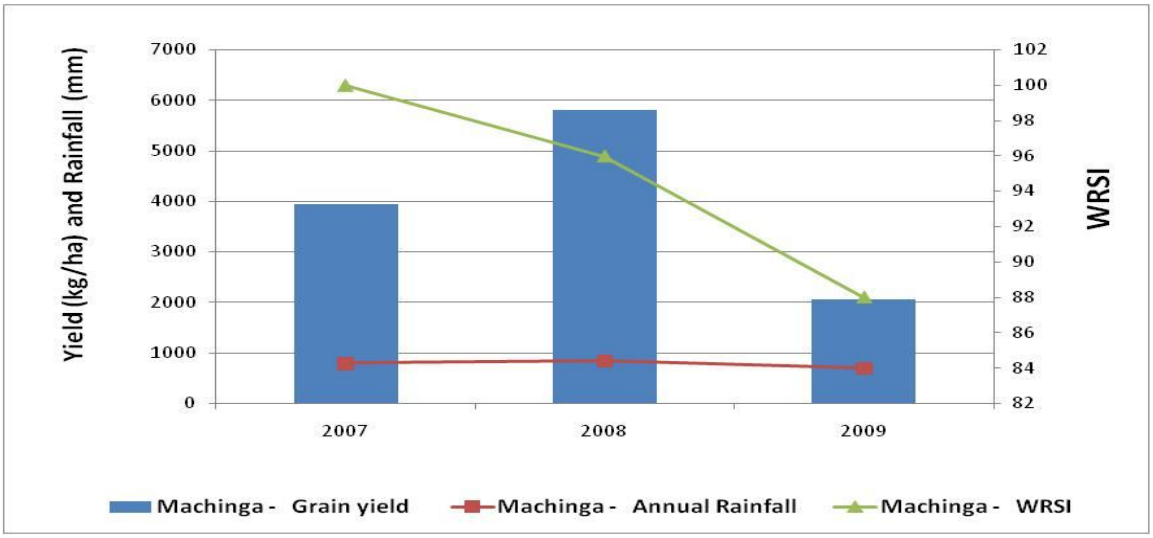


Figure 4.2-10 : Yield -WRSI – Rainfall relationship for Machinga district at farmer level.

Nkhotakota District

Nkhotakota had farmers from 2006 to 2009 (Figure 4.2-11). The 7 farmers in 2006 were predicted to have very good crop performance with yields >100% of their potential. The average grain yield realized was 90% of the potential, with the yield having no relationship to the WRSI. When regressed separately, grain yield was decreasing with an increase in annual rainfall, even though this relationship was not significant.

Harvest year 2007 had 7 farmers, some of whom were to have very good others good crop performances. The first lot had 58% against a prediction of >100%, while the second lot had 67% against a predicted 90-100%. In this year, grain yield decreased with an increase in the index as well as annual rainfall; though this effect was found not to be statistically significant.

Harvest year 2008 had 6 farmers, all of whom were predicted to have very good crop performance. The actual yield was 88% against the predicted >100%. There was no statistical relationship between the predictions made under the index and the grain yield. Average grain yield decreased with an increase in rainfall.

The 7 farmers in harvest year 2009 were in two categories: very good and good. In both cases, the actual grain yields were in line with the predictions, *i.e.* 120% against >100%; 130% against 90-100%. Even though the predictions were true, the grain yield is decreasing with an increase in the index. The yield is however increasing with an increase in annual rainfall, though both parameters are not statistically significant.

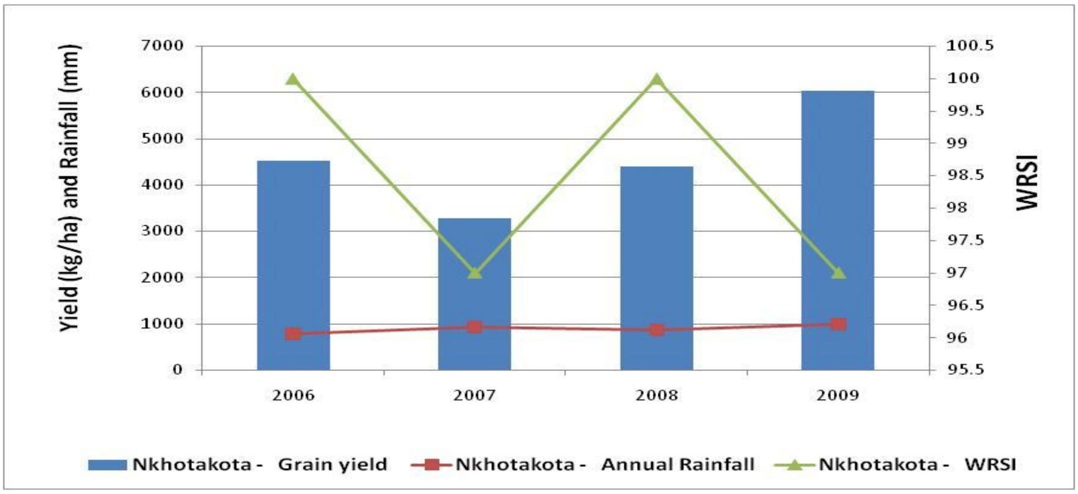


Figure 4.2-11 : Yield -WRSI – Rainfall relationship for Nkhotakota district at farmer level.

Zomba and Salima District

The farmers in Salima and Zomba district had been involved in conservation agriculture for 3 years. The grain yields records available however were only for one year.

Salima district had 6 farmers who were predicted to have very good crop performance. The average grain yield for Salima was 129% and was in line with the prediction of >100%. The yield however was decreasing with an increase in the index.

Zomba district had 3 farmers in 2008 who were predicted to have good crop performance. The actual yield for Zomba was 84% which was lower than the predicted 90-100%. The prediction showed that yield would decrease with a decrease in the index even though this decrease would not be statistically significant.

In both districts there was no statistical relationship between the average grain yield and the annual rainfall.

Summary on Average Grain Yield, WRSI and Annual Rainfall Relationships at Farmer Level

In summary, combining all the districts across the 5 seasons, 10 out of 26 predicted crop performances were true. Out of these 10 predictions, only 1 for Dowa in 2009 was statistically significant. Table 5.2-1 gives a summary of the relationship between average grain yield and the water requirement satisfaction index.

The combined relationship of the average WRSI and the average grain yield across the years in all district (Figure 5.2-12) has an $R^2 = 0.5$. The general trend was that yield would increase with an increase in the WRSI up a point, even though not always statistically significant. The WRSI measures how well the crop water requirement was satisfied in a season, thus the higher the index the more the crop would have been satisfied. Since the WRSI relates to rainfall in rain fed agriculture, this satisfaction can only be up to a certain rainfall threshold beyond which the rainfall may be way above the crop water requirements.

Table 4.2-1 : Analysis of Yield in Relation to the WRSI

District	Harvest Year	WRSI	Expected Crop Performance (%)*	Average Grain Yield	Actual Crop Performance 1 (%)**	Actual Crop Performance 2 (%)***	Variance (%)
Balaka	2005	97	90 – 100	2169	72	43	52
Balaka	2005	100	100	3986	133	80	15
Balaka	2006	97	90 – 100	3364	112	67	28
Balaka	2007	100	100	3989	133	80	15
Balaka	2008	97	90 – 100	4244	141	85	10
Balaka	2008	100	100	3776	126	76	19
Balaka	2009	84	50 – 90	2207	74	44	26
Balaka	2009	99	90 – 100	3006	100	60	35
Balaka	2009	100	100	2730	91	55	40
Dowa	2006	100	100	4178	139	84	11
Dowa	2007	97	90 – 100	7307	244	146	-51
Dowa	2007	100	100	8953	298	179	-84
Dowa	2008	100	100	6219	207	124	-29
Dowa	2009	99	90 – 100	4411	147	88	7
Dowa	2009	100	100	5256	175	105	-10
Machinga	2007	100	100	3931	131	79	16
Machinga	2008	96	90 – 100	5800	193	116	-21
Machinga	2009	88	50 -90	2050	68	41	49
Nkhotakota	2006	100	100	4522	151	90	5
Nkhotakota	2007	97	90 – 100	3347	112	67	28
Nkhotakota	2007	100	100	2879	96	58	37
Nkhotakota	2008	100	100	4401	147	88	7
Nkhotakota	2009	97	90 – 100	6519	217	130	-35
Nkhotakota	2009	100	100	5975	199	120	-25
Salima	2009	100	100	6425	214	129	-34
Zomba	2008	86	50 – 90	4192	140	84	-14

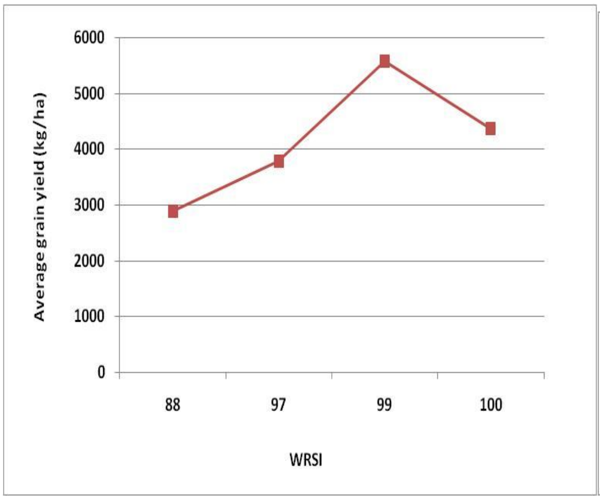
**Expected crop performance as per interpretation of the water requirement satisfaction index.*

*** Actual crop performance as a percentage of the expected average grain yield for hybrids in Malawi under local management.*

****Actual crop performance as a percentage of the maximum potential grain yield for hybrids in Malawi under local management.*

Variance (%) = Average (Expected crop performance upper limit – Actual crop performance 2) (Expected crop performance lower limit – Actual crop performance 2)

Annual rainfall was used as a parallel indicator for crop performance. The relationship between annual rainfall and grain yield was similar to that between the WRSI and the grain yield. The average grain yield increased with an increase in the annual rainfall up to a point (Figure 5.2-12). The increases occurred within the 500 – 800 mm / annum thresholds which were suggested by Doorenbos *et al*., (1986) and Pacey *et al*., (1986).



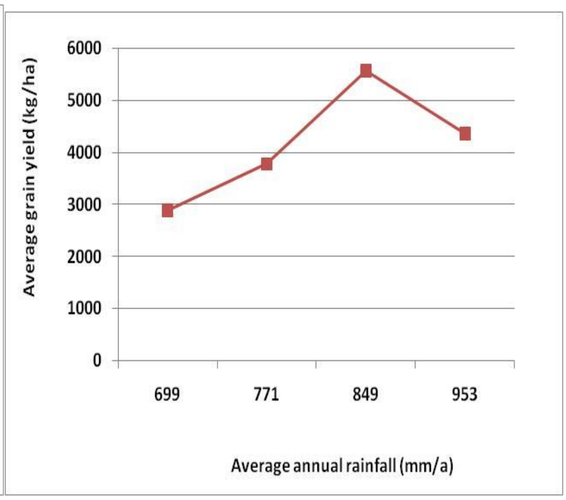


Figure 4.2-12 : Summary of Yield – WRSI, Yield – Average Annual Rainfall at Farmer Level

4.3 Analyses on Grain Yield

4.3.1 Yield Gains from Conservation Agriculture

One of the specific objectives of this study was to determine if there are any differences in the average grain from conservation agriculture and conventional farmers practice. This was based on the hypothesis that conservation agriculture will give higher net benefits when compared with conventional farmer practices. An analysis was therefore done to determine the gains obtained from CA.

Yield gains (as a percentage) for each farmer were calculated for the two conservation agriculture treatments with respect to the farmers check. These calculations were based on equation 3:

$$\textbf{Yield gain (\%)} = \{(CA - CT) / CT\} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{ Equation 3}$$

Where

CA : Yield from conservation agriculture

CT : Yield from conventional tillage

The farmers check was in this case used as the baseline to calculate yield gains obtained from the two conservation agriculture treatments. The objective of these calculations was to find out if conservation agriculture had performed better than the conventional practice.

These analyses also explores for possible relationships between conservation agriculture and rainfall. Pacey *et al*., (1986) suggested that runoff farming gives the best returns in an average annual rainfall of between 500 - 600mm. The analyses were also done to see if indeed conservation agriculture would perform better within or outside this bracket.

A third aspect of these analyses was based on the hypotheses that maize will perform best within an annual rainfall of 500 - 800 mm (Doorenbos *et al*., 1986). Following the argument above, if maize is grown under conservation agriculture, the rainfall has to be within 500 - 800mm bracket for a farmer to get optimum yields. This hypothesis assumes all other factors of maize production are constant.

Balaka District

The yield gain from conservation agriculture in Balaka district varied across the period under study. The maximum yield gain from the conservation agriculture treatment occurred in 2005 and was 560%. The highest yield gain from the reduced tillage treatment also occurred in 2005 and was 360%. The least gain from the two treatments occurred in 2006, in which case the farmers check performed better than the conservation agriculture. In this year, the grain yield from farmers check was 61.85% higher than reduced tillage and 60.81% higher than conservation agriculture.

The average gains for Balaka are within the range of 23% to 270% for reduced tillage and 33% to 140% for conservation agriculture treatment. Figure 4.3-1 shows that harvest year 2006 which had the lowest gains from CA, had the highest average rainfall among the five years under study. The average annual rainfall of 943mm is outside the 500-600 mm/annum which is the suggested threshold for runoff farming (Pacey *et al*., 1986); and 500-800 mm/annum as the threshold for maize production (Doorenbos *et al*., 1986). Harvest year 2005 had the lowest rainfall among the 5 years under study and the highest yield gains from CA. This may be an indication that CA may give higher gains in low rainfall regimes; this hypothesis however is not necessarily conclusive from this study.

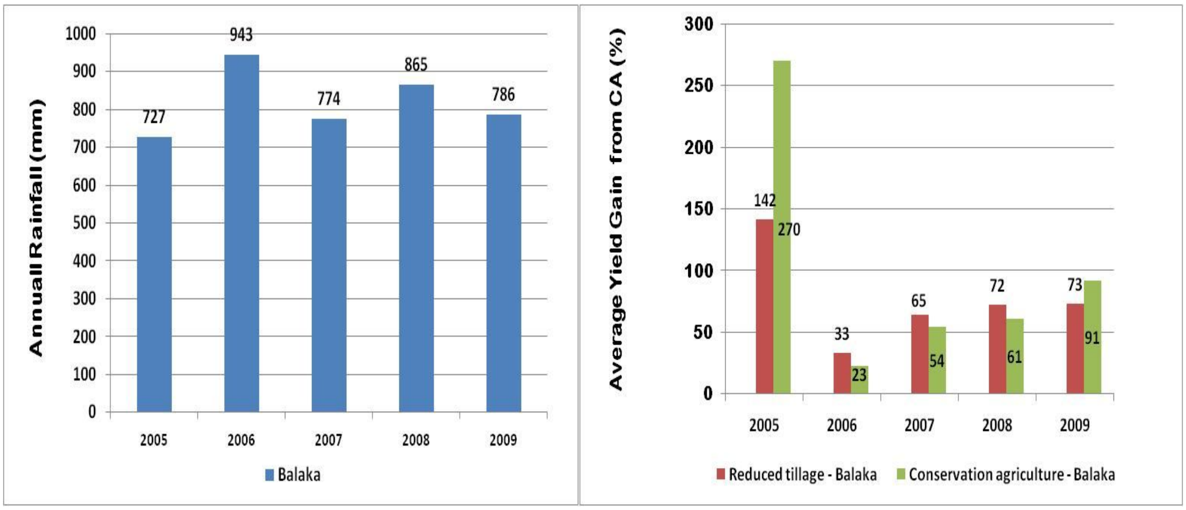


Figure 4.3-1 : Yield gain from conservation agriculture in Balaka district

Dowa District

The highest yield gains from the conservation agriculture plot in Dowa was up to 34% and occurred in 2008; while the highest for the reduced tillage plot was 45% and occurred in 2006. The harvest year 2007 had occurrences of the lowest gains from the conservation agriculture plot. The yield gain from the CA plot in this year was 50% while that from the reduced tillage plot was 47%. This implies that with some farmers, the farmers check was 50% and 47% better than the CA and reduced tillage plot respectively (figure 4.3-2).

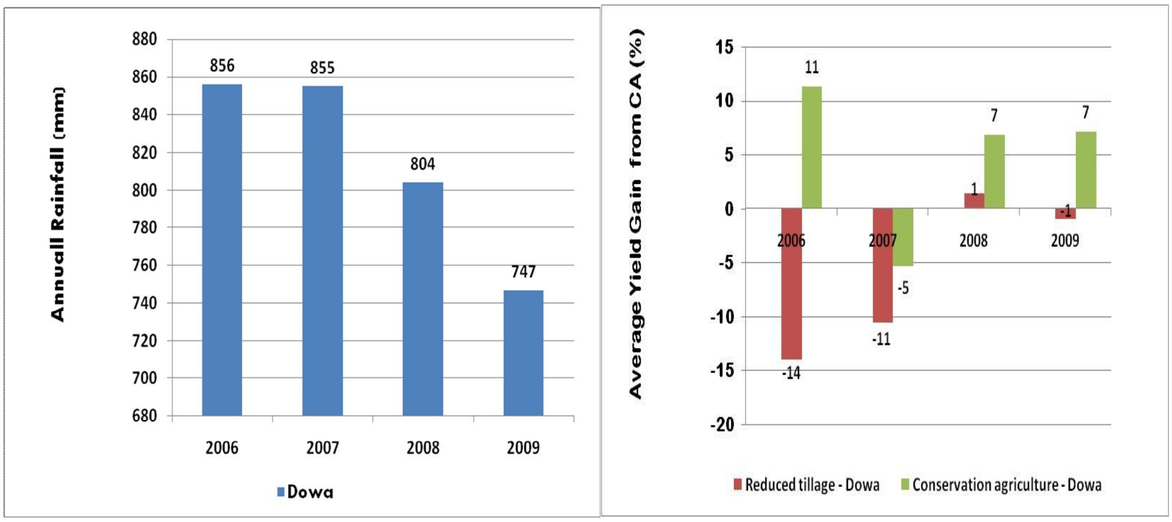


Figure 4.3-2 : Average yield gain (%) from conservation agriculture in Dowa district

Generally, the CA plot did not do well in Dowa as the average yield gains in 3 out of 4 years under study were negative. This means in 3 out of 4 years, the grain yield from the farmers check was higher than that from the CA plot. The Dowa performance of the CA agrees with Pacey *et al*., (1986) who define the rainfall threshold in which runoff farming is productive as being 500-600 mm / annum. The deviation from this threshold however is not very different from Balaka district, whose yield gains were much higher. The poor performance of the CA plot in Dowa with reference to rainfall may suggest that crop performance is determined by other factors as well. Timing of operations such as weeding, fertilizer application, time of planting may have affected the performance of the technology.

The reduced tillage plot however had positive average yield gains from CA, even though when compared with Balaka district, the yield gains are still lower. This may have negative implications on the adoption of the technology by the farmer.

Machinga District

Machinga is the only district which has positive gains from the two conservation agriculture treatments throughout the study period. The highest gains for both treatments occur in 2007, and are 352% for the CA plot and 344% for the reduced tillage plot. The least gain occured in 2009 where the CA plot was only 3% better than the farmers check and the reduced tillage was 16% better than the farmers check. Unlike in Balaka district, where CA generally performed better in low rainfall, in here CA performs better in medium rainfall. Medium rainfall in this case only referring to the annual average rainfall that is "medium" amidst the three years under study (Figure 4.3-3).

The average yield gains from the CA plot range from 64-174% while that from the reduced tillage range from 73-187%. It should be noted that the gains from the reduced tillage are consistently higher than the CA plot. The yield gains in Machinga are high enough and can easily be used in the advancement of the CA technology in the district. The only challenge is that the gains are decreasing with time for both plot treatments, which can be a threat to the continuation of the technology by a farmer.

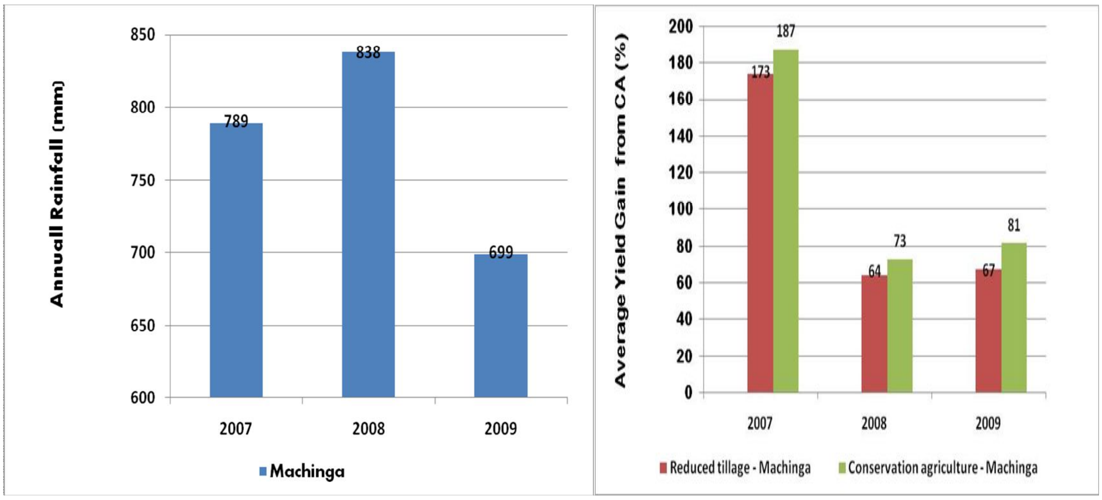


Figure 4.3-3 Average yield gains from conservation agriculture in Machinga district

Nkhotakota District

The highest yield gain from the CA plot occurred in 2007 and was 280%. The lowest yield gain was -16% which was in 2008. The average yield gain had a range of 0.5% – 74% across the 4 years under study (Figure 4.3-4).

The highest yield gain from the reduced tillage plot occurred in 2006 and was 223% while the lowest was -35% which occurred in 2008. The average gain ranged from -3% to 87%. The yield gains from the reduced tillage plot are rather low which resulted in pulling the average range into the negative zone. The farmers check performed fairly better than both CA treatments in 2008.

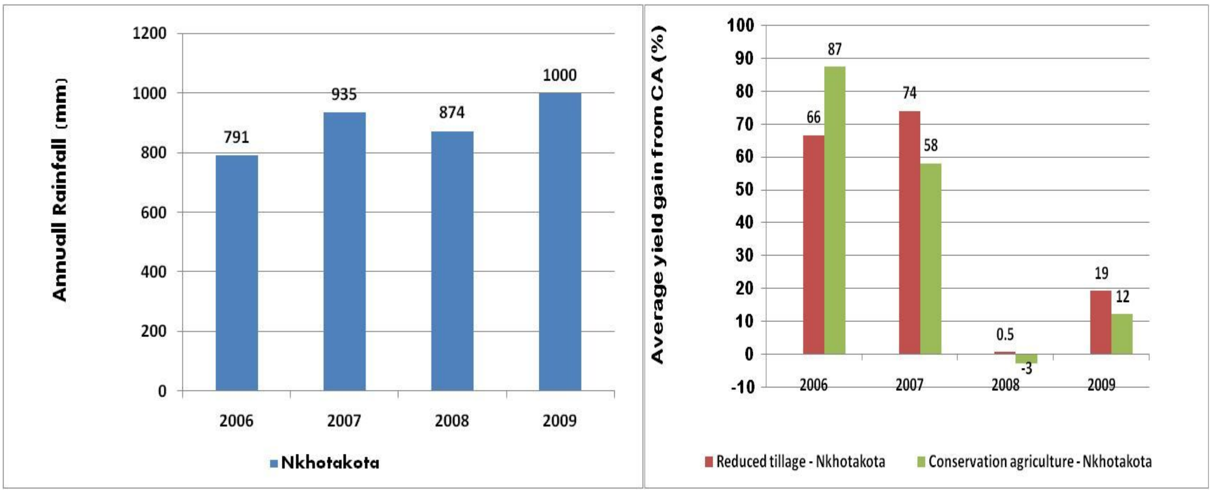


Figure 4.3-4 : Average yield gain (%) from conservation agriculture in Nkhotakota district

Out of the 4 years under study, the two treatments were expected to have performed better in 2006 whose rainfall was within the 500 – 800mm bracket (Figure 4.3-4) (Doorenbos *et al*., 1986; Pacey *et al*., 1986). This argument assumes all other factors of maize production have been taken care of, and rainfall is the deciding factor for levels of production. The average yield gains from both treatments show that CA performed better in this year; while 2008 had the worst average performance despite having the next best rainfall close to the defined bracket.

Salima and Zomba

The highest yield gain for Salima district was 73% from the reduced tillage treatment while 28% from the CA treatment. The lowest gain in the same year was -10% from the reduced tillage and -25% from the CA treatment. The average gain for reduced tillage was 25%, while the avarage for CA treatment was -2%, giving the farmers check a better performance than the CA treatment.

The highest yield gain for Zomba was 37% and came from the reduced tillage treatment; while the highest gain from the CA plot was 28%. The least gain from the two treatments was -28%, which is lower compared to that of Salima. The average gain from reduced tillage tillage was 11% while that from conservation tillage treatment was 3% (Figure 4.3-5).

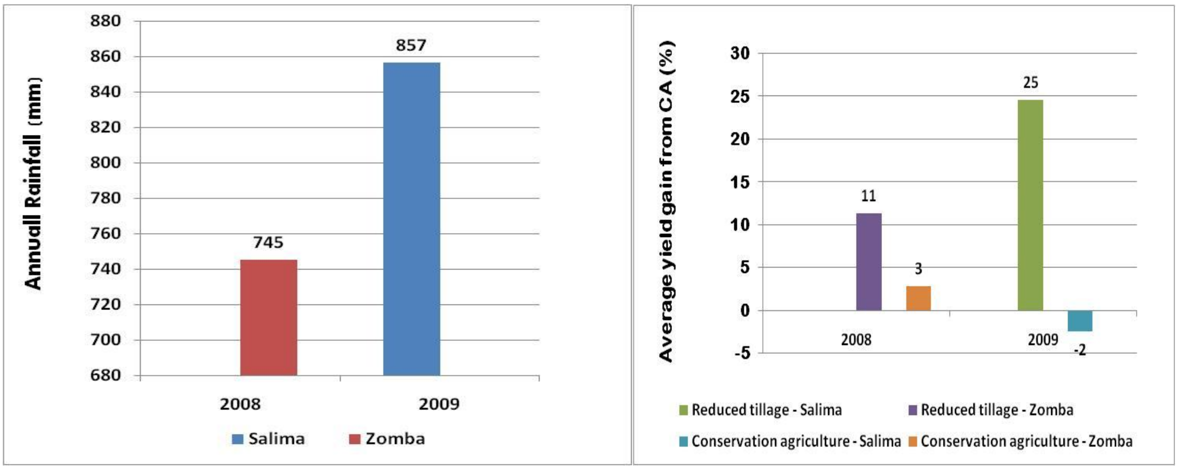


Figure 4.3-5 : Average yield gain (%) from conservation agriculture

The average rainfall for Salima falls outside the 500-600mm bracket suggested by Pacey, *et al*., (1986) and may explain the negative gains accrued from the CA treatment. However even though Zomba had rainfall outside the bracket, it had positive gains for both CA treatments.

Summary on Yield Gains from Conservation Agriculture

The yield gains from conservation agriculture varied from one district to another and from year to year. Machinga was the only district which had positive gains throughout the study period. This means that the two CA treatments performed better than the farmers check in all the years.

The overall picture however is that 2005 had the highest yield gains from both CA treatments and the lowest rainfall (Figure 4.3-6). When all the districts have been combined, the average annual rainfall in 2005 was 727mm. Even though this rainfall falls outside the bracket for runoff farming (Pacey *et al*., 1986), it has yield gains that are over 150% the other years whose average annual rainfall is above 800mm.

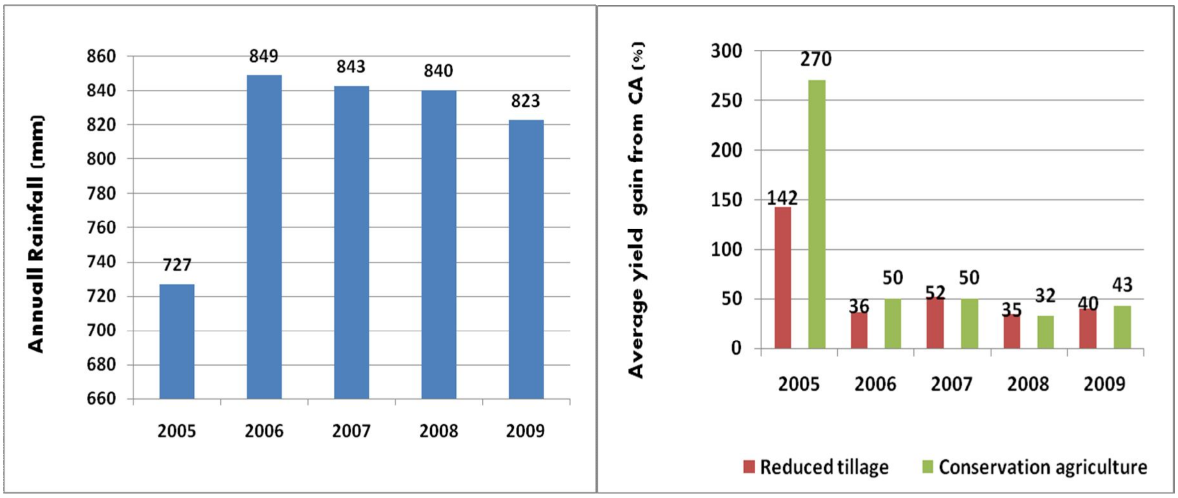


Figure 4.3-6 : Average yield gains in all study districts

The number of negative gains from the two treatments also decreases with time (Figure 4.3-6). That is the number of times that the grain yield from the farmers check is higher than the two CA treatments is decreasing with time. There is a better consistency of this in the reduced tillage treatment. This is an indication that CA, particularly reduced tillage, improves grain yield as compared to conventional farmers practice.

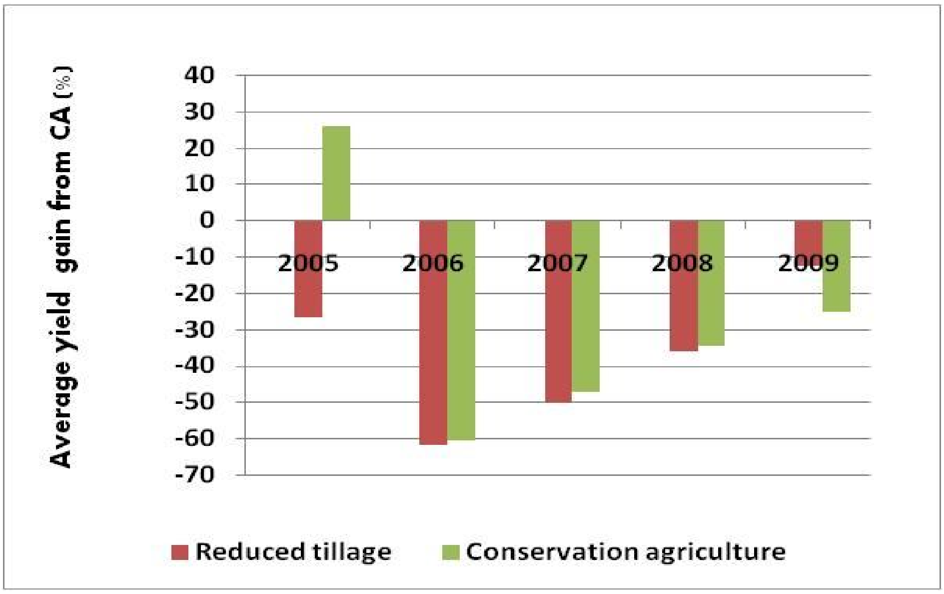


Figure 4.3-7 : Yield gain from conservation agriculture in all district

4.3.2 Plot Treatment - WRSI Interactions Across the Years

This section looks at the relationship among the grain yield from the three treatments as well as against the WRSI. From the computation made, the WRSI for the 3 plots for a given farmer in a given year is the same. In some cases, adjacent farmers in a district are also having WRSI that are very similar, if not the same.

Regression analyses were run to establish how much increase or decrease there was in the average grain yield in relation to the WRSI. The nominal differences between grain yield from the farmers check, reduced tillage and conservation agriculture plots are established. At this stage, the hypothesis is that the average grain yield should increase with an increase in the WRSI.

In harvest year 2005, combining all the districts, a unit increase in the WRSI caused an increase of 605 kg/ha in the grain yield. The average grain yield from the farmers check was 3070 kg less than that from conservation agriculture. Average grain yield from reduced tillage was 1959 kg less than that of conservation agriculture. Grain yield increases as we move from the farmers check to conservation agriculture, but no treatment is statistically superior. Neither did the WRSI have any significant relationship with the grain yield.

In harvest year 2006, combining all the districts, a unit increase in the WRSI led to an increase of 343 kg/ha. This increase was statistically significant at p = 0.05. The average grain yield from conservation agriculture was 865 kg/ha higher than farmers check. The average grain yield from reduced tillage was 297 kg/ha more than farmers check. In this year grain yield increases as we move from farmers check to conservation agriculture, but none of the treatments was statistically superior.

In harvest year 2007, combining all the districts, a unit increase in the WRSI led to a decrease in grain yield by 609 kg/ha. This decrease was statistically significant at p = 0.05. The average grain yield of conservation agriculture was 793 kg/ha greater than that from farmers check. The average grain yield from reduced tillage is 609 kg/ha higher than that of farmers check. In this year therefore, there is no treatment that is statistically superior.

For harvest year 2008, across all the districts, a unit increase in the WRSI led to a decrease of 56 kg/ha in the average grain yield. This decrease cannot be explained statistically as it is not significant. The average grain yield from conservation agriculture is 990 kg/ha higher than of farmers check The average grain yield of reduced tillage is 1113 kg/ha higher than that of conservation agriculture. Both these differences are statistically significant at p = 0.05. In that year, reduced tillage is statistically superior conservation agriculture and farmers check.

In harvest year 2009, a unit increase in the index would cause a significant increase in the average grain yield of 218 kg/ha. The average grain yield from conservation agriculture is 618 kg/ha higher than farmers check. While the average grain yield of conservation agriculture is 209 kg/ha less than that of farmers check. Grain yield in this year thus decreases from reduced tillage to conservation agriculture then farmers check, even though the differences between the plots are not statistically significant.

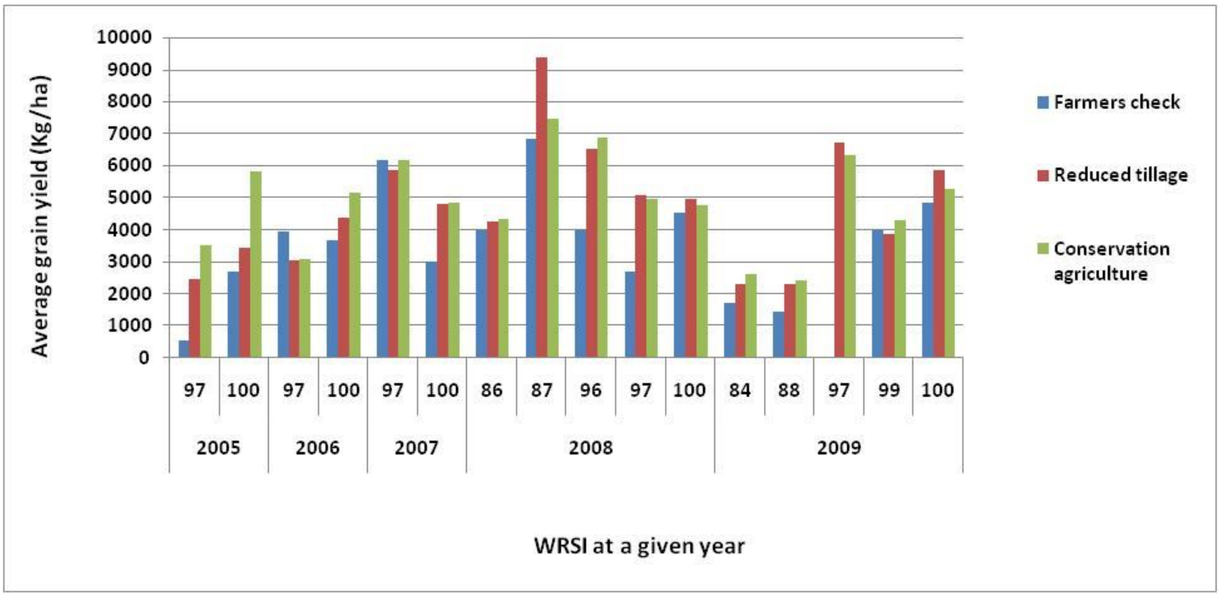


Figure 4.3-8 : Summary of grain yield - WRSI interactions at farmer level.

4.3.3 Plot Treatment - WRSI Interactions within a District

The average grain yield from each of the 3 treatments was regressed against a particular WRSI in a district. From the WRSI computations, it was shown that the 3 plots would have the same WRSI recording in a given harvest year (Annex 2). This implies that the crop water requirement for each of the 3 treatments, for a particular farmer, in a given year, was roughly satisfied equally. This regression was therefore done to establish the differences in yield on the 3 plots; having received roughly the same amount of water. The objective of the analysis at this level was to establish if there was a treatment that was consistently and statistically superior across the years of study in a given district. Each district was regressed separately to account for the differences in agro-ecological zones.

Balaka District

In harvest year 2005, there were 12 observations all at index 97. At this index, the average grain yield from conservation agriculture was higher than farmers check and reduced tillage. In harvest year 2006, the average grain yield of conservation agriculture is lower than farmers check but higher than reduced tillage. These differences are not significant.

Harvest year 2007, had 24 observations all at index 100. In this year the average grain yield of conservation agriculture plot is less than farmers check, significant at $p = 0.05$. The average grain yield of the CA plot is however less than that of reduced tillage but not statistically significant. Harvest year 2008 had two indices 97 and 100. At both indices, the average grain yield from the conservation agriculture plot is higher than farmers check but lower than reduced tillage. These differences are also not significant.

The harvest year 2009 had 3 indices 84, 99 and 100. At all indices, the average grain yield from the conservation agriculture plot is higher than that of the reduced tillage and farmers check. All the observations are not statistically significant except the CA plot and farmers check at index 100. From the observations of the 4 years, there is no plot that is consistently and statistically superior.

Dowa District

In harvest year 2006 Dowa district had the WRSI as 100. The average grain yield for the conservation agriculture plot was higher than that of reduced tillage and farmers check. The difference between farmers check and conservation agriculture was not significant, but for reduced tillage and conservation agriculture it was significant. Harvest year 2007 had two indices 97 and 100. At index 100, the average grain yield from conservation agriculture is higher than that of reduced tillage but lower than that of farmers check. At index 97 the average grain yield from conservation agriculture is higher than that of reduced tillage and farmers check. At both indices, the differences are not significant.

The harvest year 2008 had one index 100 on which average grain yield from conservation agriculture was higher than that of reduced tillage and farmers check. In harvest year 2009 Dowa had two indices 100 and 99. At both indices, the average grain yield from conservation agriculture was higher than that of farmers check and reduced tillage. In both years, reduced tillage becomes second to conservation agriculture, but the differences are not statistically significant. There is no treatment that is consistently and statistically significant in its yield.

Machinga District

The regression for Machinga shows some level of consistency. The index for harvest year 2007, 2008 and 2009 were 100, 96 and 88 respectively. In all the years, the average grain yield from conservation agriculture is higher than that of reduced tillage and farmers check. The difference is highest between conservation agriculture and farmers check and significant at $p = 0.05$. This also relates with yield gains discussed earlier. Machinga was the only district whose yield gain from CA with respect to farmers practice was positive throughout the study period. The difference between conservation agriculture and reduced tillage is not significant.

Nkhotakota District

The harvest year 2006 had 21 observations and index 100. The average grain yield from conservation agriculture was higher than that of reduced tillage and farmers check. Only the difference between conservation agriculture and farmers check was significant at $p = 0.05$. In 2007, at index 100 and 97, average grain yield from conservation agriculture was higher than that of farmers check but less than that of reduced tillage. For harvest year 2008 the average grain yield from conservation agriculture is lower than that of reduced tillage and farmers check, with that of farmers check being higher than that of reduced tillage. In harvest year 2009, the average grain yield from conservation agriculture is higher than farmers check but less than reduced tillage. In all the years, the differences were not significant.

Salima and Zomba districts

There was no statistical relationship between the index and the yield in Salima and Zomba districts. The average grain yield increased from farmers check to conservation agriculture in both districts. There was no treatment that was statistically superior in these districts.

Summary on Plot Treatment -WRSI Interactions

When all these 5 harvest years have been combined, there is no treatment that is consistently and statistically superior to the others. Theoretically, the conservation agriculture plot, which had a legume, was expected to be superior (Erenstein, 2003). The average yield from conservation agriculture is generally seen to be higher, but there is no consistency in the level of significance to conclude its superiority across the 5 years.

For the majority of the farmers in this study (70%), 2009 was year 3 of practicing CA, the rest were in year 4 and 5. Depending on previous land use, how degraded the soil fertility was, and the combination of CA practices shown, there may not be significant improvements in the yields (Figure 4.3-9) until year 5 of CA (Giller *et al*., 2009). There have even been incidences of depressed yields during the first years of CA, compared to non CA yields. These could be some of the reasons why neither of the plots under CA could not be consistently and statistically superior as expected.

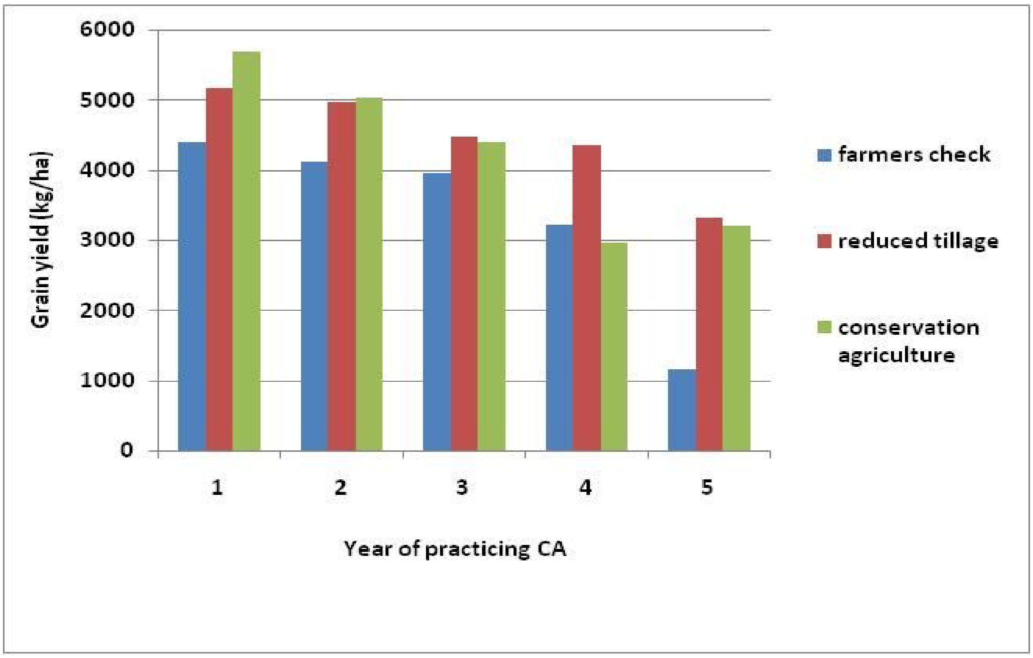


Figure 4.3-9: Average grain yield by year of practicing CA

This result may have a negative implication in the promotion of the technology. The extension worker would have to be frank and help the farmer make an informed decision in as far as adoption of conservation agriculture is concerned. That is to say farmers have to be aware that yield improvements do not come in the first year of adopting conservation agriculture.

4.4 General Discussion on the Yield – WRSI Interactions

The first observation that can be made is that the AgroMetShell was developed as a tool for yield forecasting and prediction i.e. early warning purposes. In this case, the computation of the Water Requirement Satisfaction is done before the cessation of the rains. The yield prediction for early warning is derived from multiplying the WRSI with an intercept constant and a coefficient. This study however computed the WRSI at harvest, when the rainfall season was complete, and did not use the intercept and the constant. It is possible that computing the WRSI at harvest, without the use of the intercept and constant may have contributed to the index not having the expected relationship with yield.

The input parameters for computing the WRSI in AMS include: Dekadal actual and normal rainfall; Dekadal actual and normal PET; and a Crop Parameter file which contains information on: Crop coefficient, Planting dekad (PLD), Crop Cycle length (CYL) in Dekads, and Soil Water Holding Capacity. These input parameters assume that crop management (e.g time of planting, fertilizer applications, pest and disease control) would have a marginal effect on the yield. It is possible however that in some of years under study, management may have affected crop yields despite having the crop water requirement satisfied fully.

The history of the development of the AMS has a strong lean towards establishing the effects of water deficits to yield. Thus it becomes more sensitive to water deficits. It is also possible that in some years where the WRSI gave expected crop performances of more than100, there may have been too much rainfall. Maize requires an annual rainfall of 500 – 800mm (Doorenbos *et al*., 1986) and CA an annual rainfall of 500 – 600mm. In a number of years, the average annual rainfall was seen to be above this range. The WRSI for a number of years with rainfalls above this range were seen to be 100 (Annex2 and 3).

One WRSI reading, 97, is singled out (randomly) across the years. It turns out that in each year, this reading has different annual rainfall figures (Figure 4.4-1). The rainfall ranges from 727 to 1080 mm/annum, which may confirm that the computation of the WRSI may not be sensitive to excess water. If it were, we would expect specific WRSI outcomes in specific rainfall ranges.

The interpretation of the WRSI in this case is debatable, because the crop water requirement may have been satisfied fully, but there may also have been too much water, which the index is not able to show. Unless it can be proven that the soils were well drained to release all the excess water, (which was beyond the scope of the current paper) it is possible that in some cases where the WRSI was 100 may have been accompanied by water logging which is not healthy for tha plant. Hence the outcome of having actual crop performances that were contrary to what was predicted.

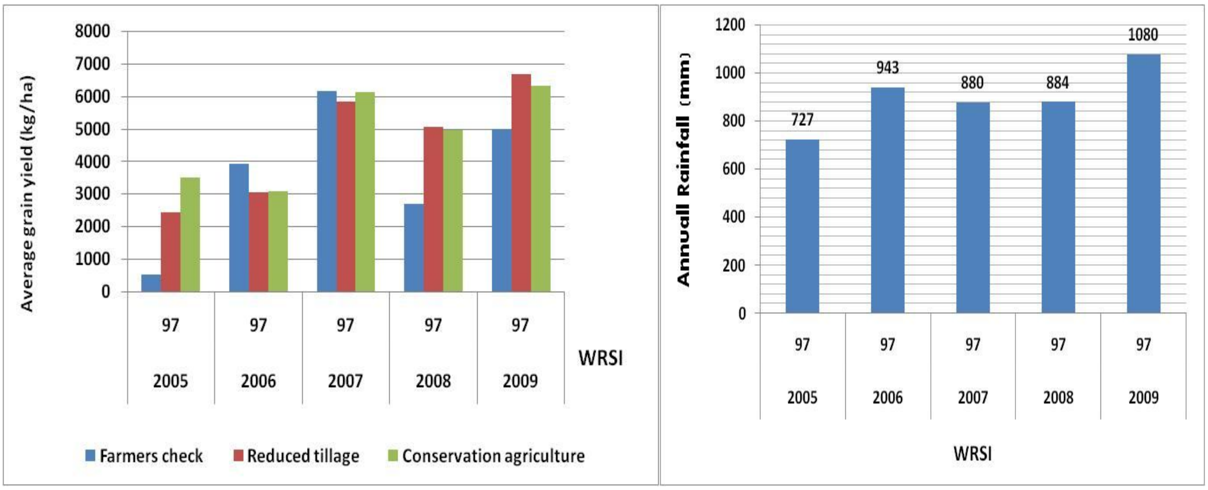


Figure 4.4-1 : Summary of average grain yield - rainfall - WRSI interactions

The insignificance of the predicted crop performances could also indicate that grain yield is a function of many parameters that must be carefully integrated if a farmer is to attain optimum yields. The WRSI has a lean towards factors to do with water. The results found in this study may indicate that just providing the crop with the water that it requires does not guarantee optimum yields.

The computations of the WRSI done in this study required historical records. Rainfall data (for 40 years) was obtained from the Meteorology Department; maize yield data at EPA level (for 25 years) was obtained from FewsNet Malawi; maize yield data at farmer level (for 5 years) was obtained from CIMMYT. Having such a diverse source of data may have increased the error term.

Martin *et al.*, (2000) carried out a study where one of the components was to validate the WRSI by comparing the annual WRSI to historical yield records. The correlation between historical yields and the WRSI in the Martin *et al*., (2000) study was 0.63 and 0.61 for Zimbabwe and South Africa respectively. This correlation was however only achieved after de-trending the historical yields and the WRSI, and normalizing both parameters to a standard deviation of one and a mean of zero.

This Martin *et al*., (2000) study provides insights on how to improve the WRSI if it is to be used for establishing post harvest yield – water stress relationships. That is, the historical yields and the WRSI have to be de-trended, but also that the WRSI has to include soil fertility parameter (Jackson, 1989). Besides moisture, soil nutrients are often an important constraint on plant growth among many smallholder farmers in sub-Saharan Africa (Martin *et al*., 2000). Thus including a nutrient aspect in the WRSI may improve it further to be used in establishing historical yields – water stress relationships.

4.5 Observations on Soil Parameters

A soil analysis was done to determine the difference in soil characteristics between CA and non CA plots. The analysis was done based on the hypothesis that conservation agriculture improves the physical characteristics of the soil with time. A total of 18 farmers were sampled. Each of these farmers was in year 3 of CA. The following were the observations made.

4.5.1 Soil Texture

Soil texture in this study refers to the amount of sand, silt and clay particles present in the soil matrix. It follows the general descriptions of a soil either being sandy, clayey, or loamy depending on the proportions of the particles present.

The soils in Balaka district are mostly sandy and sandy clay loam. In Dowa district, the soils are loamy sand. In Machinga district, the soils were found to be loamy sand and sandy clay loam. In Nkhotakota, Salima and Zomba, the soils were found to be loamy sand.

Soil texture plays an important role in the water balance of any given soil, both within the rooting depth and beyond (Gommes, 2002). Soil water balance so defined as the processes a raindrop goes through in interacting with the atmosphere, the soil, the plants and then back to the atmosphere. After a rain drop has fallen, it will either infiltrate into the soil, will be intercepted by leaves, or will be carried away as runoff. One of the targets of conservation agriculture is to enhance the amount of raindrops that infiltrate into the root zone; and to ensure this water becomes available to the plant. Thus the water balance function of interest here is the amount of rain drops that infiltrates into the soil and is retained as soil water.

Sandy soils will generally have high infiltration rates and potentially low retention rates when thoroughly wet. Clay soils on the other hand will have very slow infiltration but potentially high retention rates when thoroughly wet (Gommes, 2002). The amount of each of these particles present would thus determine the level of effort a farmer may require to enhance infiltration and retention rates. The farmers in Balaka district for example, whose soils are mostly sandy, would not require much effort to enhance infiltration; but would require much effort to retain this water within the root zone so it is available to the plant.

The ultimate role that soil texture plays however will also depend on other factors such as the water holding capacity, the underlying parent material, the level of the water table; and whether there are hard pans present or not; among others.

4.5.2 Bulk Density

The soil bulk density for all the 18 farmers was observed to be between 0.95 g/cm^3 – 1.78 g/cm^3, which is within the expected range for most soils of between 1.0 g/cm^3 and 2.0 g/cm^3.

For the farmers in Balaka and Machinga districts, the bulk density for reduced tillage and conservation agriculture are higher than that of farmers check. For Zomba and Salima, the bulk density of reduced tillage is lower than that of farmers check; while the bulk density of conservation agriculture plot is higher than farmers check. In Nkhotakota and Dowa districts, the bulk density of conservation agriculture is lower than that of farmers check, while the bulk density of reduced tillage is higher than farmers check. All these differences were not statistically significant. Table 5.5-1 is a summary of the average bulk densities for each of the plot treatments in each district.

Table 4.5-1: Average bulk densities for each district

District	Average of Bulk Density (g/cm^3)		
	Farmers check	**Reduced tillage**	**Conservation agriculture**
Balaka	1.41	1.46	1.42
Dowa	1.36	1.37	1.24
Machinga	1.38	1.40	1.40
Nkhotakota	1.50	1.43	1.60
Salima	1.34	1.28	1.40
Zomba	1.53	1.51	1.57

The CA plot with a legume was expected to have the lowest bulk density as it has comparatively more organic matter being added to it from crop residues and legume incorporation.

This observation however tallies with results observed elsewhere in Malawi, where the bulk density of soils under farmers practice was lower than that under CA even after 4 years (Kamwendo, 2009). Since soil build up takes time, it can perhaps be inferred that the bulk density of the soil may not change much even after 4 years of CA. Thus a farmer will have to wait much longer for their aggregate soil structure to start showing significant improvements.

Compaction is one of the factors that leads to higher soil densities. Soil compaction was observed during the first years of no till or reduced tillage due to reduction in soil pore volume in the absence of tillage (Jin *et al.*, 2008; Bhattacharyya *et al.*, 2009). This increase in bulk density appears to be only temporary, with the initial compaction compensated later by the development of soil pores originating from soil biological activity (Kamwendo, 2009).

4.5.3 Field Capacity

The field capacities for the 18 farmers range from 2-42%. In Balaka and Dowa districts, the field capacity of farmers check is higher than that of reduced tillage and conservation agriculture, with the latter plot having the lowest field capacity. For Salima and Zomba, farmers check is at lower field capacity, followed by conservation agriculture and then reduced tillage.

In Nkhotakota, conservation agriculture has the lowest field capacity, followed by farmers check then reduced tillage. In these 5 districts, the differences are not significant. In Machinga district, the field capacity of reduced tillage is significantly higher than farmers check. Conservation agriculture plot has a field capacity that is higher than farmers check but the difference is not significant. Table 5.5-2 gives a summary of the field capacities for the three different plots in each district.

Table 4.5-2 : Average field capacities for each district

District	Average Field Capacity (%)		
	Farmers check	Reduced tillage	Conservation agriculture
Balaka	8.71	9.50	6.13
Dowa	20.50	20.75	22.63
Machinga	6.25	8.50	6.75
Nkhotakota	14.75	15.50	12.38
Salima	29.00	31.50	29.75
Zomba	3.75	6.25	4.50

After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are considered to be ideal for crop growth. Field capacity also relates to the aggregate soil particles, where the higher it is, the better it gets for crop growth; particularly the circulation of water and air particles for water uptake by the roots. It thus follows that the field capacity for CA plot with legume was expected to be highest, seconded by the reduced tillage plot then farmers check. In this case however, it can also be said that the soils are still building up. Hence the effect of CA may not be significant at this time.

CHAPTER SIX

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Water Requirement Satisfaction Index was used in characterizing the rainfall season quality. Within the period of study, the WRSI showed that there would be no season of complete crop failure at farmer level, but there would be some at EPA level. A further assessment also showed that the average WRSI would increase with an increase in average annual rainfall.

The results obtained showed a weak relationship between forecasted crop performances and the WRSI. In a number of seasons, the WRSI gave an indication of average crop performances, i.e. where crop performance would be 50 - 90%. When compared with the actual yield, some years were above, while others were below this expected 50 - 90% yield range. The crop performances however increased with an increase in annual rainfall but to a point.

This study aimed at establishing if there is a relationship between the rainfall season quality as measured through the Water Requirement Satisfaction Index {WRSI} and yield. This was an attempt to see if the WRSI can be used as a criterion for implementation of conservation agriculture in a given area. The expected relationship was that the yield would statistically increase with an increase in the WRSI. It was also expected that there would be significant differences between the average grain yield obtained from conservation agriculture in relation to conventional farmers practice.

In terms of the average grain yield from conservation agriculture, there was no treatment that was consistently and statistically superior among the three plot treatments under study. The plot treatments being farmer check which simulates conventional farmer's practice, reduced tillage which embraces the principle of minimum soil disturbance and max soil cover, and conservation agriculture which embraced all the three principles of CA.

The average yield gain from conservation agriculture as compared with conventional farming practices was not consistent across the years. There were even occurrences where the conventional farmers practice performed better than conservation agriculture. The negative gains however reduced with time, meaning that the occurrences where conventional farmers' practices were better than CA reduced with time.

It is therefore concluded that the Water Requirement Satisfaction Index can be used to characterize rainfall season quality. However one has to bear in mind that this characterization will only be based on satisfaction of crop water requirements and assumes that all other factors of crop production are constant. Factors of particular interest in this case would be soil fertility and farm management.

Another conclusion drawn from this research is that historical yields may not relate well with forecasts made using the Water Requirement Satisfaction Index. That is actual crop performances may not always respond positively to what was given as a forecast by the WRSI.

It is also concluded that there may not be significant differences in the average grain yield obtained from conservation agriculture and that from farmer's practice. The farmer's practice may even perform better than CA. The instances where farmer's conventional practices perform better than conservation agriculture however decrease with time. Thus farmers will have to wait longer in order to see significant changes in their yield.

5.2 Recommendations

Based on the results obtained in this study, the following recommendations are made:

- In the promotion of conservation agriculture, farmers will have to be made aware that meaningful improvements in crop yields may not come immediately. But that yield gains from conservation agriculture with respect to conventional farmer practices will increase with time.

- Literature has shown that the Water Requirement Satisfaction Index is more sensitive to water stress conditions. This study can be replicated, where the study area would include both water stressed and those areas that are not water stressed, to test if the index can produce different results.

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ANNEX 1: Soil properties for the 18 sampled farmers

Harvest Year	District	Farmer	Silt Content (%)	Clay Content (%)	Textural class	Field capacity (%)	Bulk density (g/cm^3)	Plot No.	Plot treatment
2010	Balaka	Lughano Mwangonde	4	4	s		1.4	1	Farmers Check
2010	Balaka	Lughano Mwangonde	4	4	s	16	1.53	2	CA+Maize
2010	Balaka	Lughano Mwangonde	4	4	s	3	1.63	3	CA+Maize+cowpeas
2010	Balaka	Catherene Matindili	8	8	ls	8	1.48	1	Farmers Check
2010	Balaka	Catherene Matindili	8	4	s	8	1.54	2	CA+Maize
2010	Balaka	Catherene Matindili	4	4	s	3	1.31	3	CA+Maize+cowpeas
2010	Balaka	Emmanuel Mpando	8	12	sl - scl	2	1.55	1	Farmers Check
2010	Balaka	Emmanuel Mpando	8	8	ls	11	1.42	2	CA+Maize
2010	Balaka	Emmanuel Mpando	4	4	s	8	1.31	3	CA+Maize+cowpeas
2010	Balaka	Frank Sandason	8	8	ls	12	1.24	1	Farmers Check
2010	Balaka	Frank Sandason	8	4	s	8	1.3	2	CA+Maize
2010	Balaka	Frank Sandason	12	4	ls	9	1.24	3	CA+Maize+cowpeas
2010	Dowa	Jenitala Zuze	8	8	ls	28	1.59	1	Farmers Check
2010	Dowa	Jenitala Zuze	8	4	s	29	1.43	2	CA+Maize
2010	Dowa	Jenitala Zuze	16	8	sl	42	0.95	3	CA+Maize+cowpeas
2010	Dowa	Kilioni Sikalioti	8	12	sl	19	1.35	1	Farmers Check
2010	Dowa	Kilioni Sikalioti	0	8	s	19	1.64	2	CA+Maize
2010	Dowa	Kilioni Sikalioti	4	12	ls	17	1.36	3	CA+Maize+cowpeas
2010	Dowa	Njatani Manyozo	4	8	ls	19	1.52	1	Farmers Check
2010	Dowa	Njatani Manyozo	4	10	ls	19	1.35	2	CA+Maize
2010	Dowa	Njatani Manyozo	12	16	sl	18	1.13	3	CA+Maize+cowpeas
2010	Dowa	Chagamba Kafamveka	10	18	sl	18	1.34	1	Farmers Check
2010	Dowa	Chagamba Kafamveka	2	10	ls	18	1.22	2	CA+Maize
2010	Dowa	Chagamba Kafamveka	4	8	ls	18	1.51	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	Silt Content (%)	Clay Content (%)	Textural class	Field capacity (%)	Bulk density (g/cm^3)	Plot No.	Plot treatment
2010	Machinga	Stanley Ndege	6	8	ls	6	1.33	1	Farmers Check
2010	Machinga	Stanley Ndege	4	10	sl - scl	9	1.36	2	CA+Maize
2010	Machinga	Stanley Ndege	6	8	ls	5	1.48	3	CA+Maize+cowpeas
2010	Machinga	Edson Matika	10	10	ls - sl	4	1.38	1	Farmers Check
2010	Machinga	Edson Matika	4	4	s	12	1.37	2	CA+Maize
2010	Machinga	Edson Matika	4	8	ls	8	1.38	3	CA+Maize+cowpeas
2010	Nkhotakota	B Maleko	14	8	sl	34	1.45	1	Farmers Check
2010	Nkhotakota	B Maleko	4	10	ls	25	1.43	2	CA+Maize
2010	Nkhotakota	B Maleko	6	8	ls	6	1.66	3	CA+Maize+cowpeas
2010	Nkhotakota	Jelimoti Sikelo	4	8	ls	5	1.53	1	Farmers Check
2010	Nkhotakota	Jelimoti Sikelo	8	6	ls	5	1.51	2	CA+Maize
2010	Nkhotakota	Jelimoti Sikelo	10	6	ls	11	1.51	3	CA+Maize+cowpeas
2010	Nkhotakota	Grace Malaitcha	10	8	ls	7	1.35	1	Farmers Check
2010	Nkhotakota	Grace Malaitcha	10	6	ls	6	1.22	2	CA+Maize
2010	Nkhotakota	Grace Malaitcha	18	6	ls -sl	8	1.42	3	CA+Maize+cowpeas
2010	Nkhotakota	Ekisinala Azele	12	8	ls	6	1.7	1	Farmers Check
2010	Nkhotakota	Ekisinala Azele	8	4	s	19	1.44	2	CA+Maize
2010	Nkhotakota	Ekisinala Azele	14	6	ls	24	1.65	3	CA+Maize+cowpeas
2010	Salima	Edina Kabwabwa	8	4	s	31	1.11	1	Farmers Check
2010	Salima	Edina Kabwabwa	4	8	ls	30	1.32	2	CA+Maize
2010	Salima	Edina Kabwabwa	4	4	s	31	1.31	3	CA+Maize+cowpeas
2010	Salima	Christopher Helema	2	10	ls	30	1.39	1	Farmers Check
2010	Salima	Christopher Helema	4	8	ls	32	1.23	2	CA+Maize
2010	Salima	Christopher Helema	6	6	ls	32	1.32	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	Silt Content (%)	Clay Content (%)	Textural class	Field capacity (%)	Bulk density (g/cm^3)	Plot No.	Plot treatment
2010	Zomba	Patuma Wilson	8	22	scl	3	1.44	1	Farmers Check
2010	Zomba	Patuma Wilson	4	10	sl - scl	3	1.53	2	CA+Maize
2010	Zomba	Patuma Wilson	6	10	ls	7	1.56	3	CA+Maize+cowpeas
2010	Zomba	Alice Mainesi	6	8	ls	4	1.6	1	Farmers Check
2010	Zomba	Alice Mainesi	2	2	s	14	1.49	2	CA+Maize
2010	Zomba	Alice Mainesi	6	6	ls	4	1.35	3	CA+Maize+cowpeas

ANNEX 2 : Rainfall (mm/a), WRSI (%), Average grain yield (kg/ha) of farmers under study

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2009	Balaka	Elizabetha Belenado	767	888.7	661	100	2011.27	1	Farmers Check
2009	Balaka	Elizabetha Belenado	767	888.7	661	100	2769.94	2	CA+Maize
2009	Balaka	Elizabetha Belenado	767	888.7	661	100	3489.94	3	CA+Maize+cowpeas
2008	Balaka	Elizabetha Belenado	884	888.7	1126.4	97	2683.10	1	Farmers Check
2008	Balaka	Elizabetha Belenado	884	888.7	1126.4	97	4917.28	2	CA+Maize
2008	Balaka	Elizabetha Belenado	884	888.7	1126.4	97	3747.29	3	CA+Maize+cowpeas
2009	Balaka	Emmanuel Mpando	797	761.1	661	84	2785.19	1	Farmers Check
2009	Balaka	Emmanuel Mpando	797	761.1	661	84	2640.58	2	CA+Maize
2009	Balaka	Emmanuel Mpando	797	761.1	661	84	3124.69	3	CA+Maize+cowpeas
2008	Balaka	Emmanuel Mpando	841	761.1	1126.4	100	5113.38	1	Farmers Check
2008	Balaka	Emmanuel Mpando	841	761.1	1126.4	100	5702.32	2	CA+Maize
2008	Balaka	Emmanuel Mpando	841	761.1	1126.4	100	5823.32	3	CA+Maize+cowpeas
2007	Balaka	Emmanuel Mpando	734	761.1	975.7	100	3818.98	1	Farmers Check
2007	Balaka	Emmanuel Mpando	734	761.1	975.7	100	5539.44	2	CA+Maize
2007	Balaka	Emmanuel Mpando	734	761.1	975.7	100	5348.72	3	CA+Maize+cowpeas
2009	Balaka	flex Twaya	797	761.1	661	84	822.44	1	Farmers Check
2009	Balaka	flex Twaya	797	761.1	661	84	2184.12	2	CA+Maize
2009	Balaka	flex Twaya	797	761.1	661	84	2522.94	3	CA+Maize+cowpeas
2008	Balaka	flex Twaya	841	761.1	1126.4	100	2972.46	1	Farmers Check
2008	Balaka	flex Twaya	841	761.1	1126.4	100	3500.02	2	CA+Maize
2008	Balaka	flex Twaya	841	761.1	1126.4	100	4371.37	3	CA+Maize+cowpeas
2009	Balaka	Frank Sandason	822	841.2	661	99	2709.30	1	Farmers Check

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2009	Balaka	Frank Sandason	822	841.2	661	99	3100.20	2	CA+Maize
2009	Balaka	Frank Sandason	822	841.2	661	99	3209.12	3	CA+Maize+cowpeas
2007	Balaka	Frank Sandason	797	841.2	975.7	100	2598.52	1	Farmers Check
2007	Balaka	Frank Sandason	797	841.2	975.7	100	3504.98	2	CA+Maize
2007	Balaka	Frank Sandason	797	841.2	975.7	100	4371.73	3	CA+Maize+cowpeas
2009	Balaka	Fredson Masanje	767	898.3	661	100	1158.91	1	Farmers Check
2009	Balaka	Fredson Masanje	767	898.3	661	100	3330.83	2	CA+Maize
2009	Balaka	Fredson Masanje	767	898.3	661	100	3206.15	3	CA+Maize+cowpeas
2008	Balaka	Fredson Masanje	884	898.3	1126.4	97	3089.10	1	Farmers Check
2008	Balaka	Fredson Masanje	884	898.3	1126.4	97	2823.89	2	CA+Maize
2008	Balaka	Fredson Masanje	884	898.3	1126.4	97	3119.75	3	CA+Maize+cowpeas
2007	Balaka	Fredson Masanje	799	898.3	975.7	100	2211.22	1	Farmers Check
2007	Balaka	Fredson Masanje	799	898.3	975.7	100	4200.94	2	CA+Maize
2007	Balaka	Fredson Masanje	799	898.3	975.7	100	2439.10	3	CA+Maize+cowpeas
2006	Balaka	Fredson Masanje	943	898.3	1063.2	97	4071.79	1	Farmers Check
2006	Balaka	Fredson Masanje	943	898.3	1063.2	97	3072.30	2	CA+Maize
2006	Balaka	Fredson Masanje	943	898.3	1063.2	97	4301.64	3	CA+Maize+cowpeas
2005	Balaka	Fredson Masanje	727	898.3	526.5	97	533.33	1	Farmers Check
2005	Balaka	Fredson Masanje	727	898.3	526.5	97	2453.33	2	CA+Maize
2005	Balaka	Fredson Masanje	727	898.3	526.5	97	3520.00	3	CA+Maize+cowpeas
2009	Balaka	Grace Saizi	797	761.1	661	84	1692.64	1	Farmers Check
2009	Balaka	Grace Saizi	797	761.1	661	84	2545.48	2	CA+Maize
2009	Balaka	Grace Saizi	797	761.1	661	84	2144.08	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2008	Balaka	Grace Saizi	841	761.1	1126.4	100	3269.42	1	Farmers Check
2008	Balaka	Grace Saizi	841	761.1	1126.4	100	4545.10	2	CA+Maize
2008	Balaka	Grace Saizi	841	761.1	1126.4	100	3835.84	3	CA+Maize+cowpeas
2007	Balaka	Grace Saizi	734	761.1	975.7	100	3493.56	1	Farmers Check
2007	Balaka	Grace Saizi	734	761.1	975.7	100	5689.83	2	CA+Maize
2007	Balaka	Grace Saizi	734	761.1	975.7	100	5576.16	3	CA+Maize+cowpeas
2009	Balaka	Halord Alias	767	898.3	661	100	1087.06	1	Farmers Check
2009	Balaka	Halord Alias	767	898.3	661	100	3035.88	2	CA+Maize
2009	Balaka	Halord Alias	767	898.3	661	100	3830.06	3	CA+Maize+cowpeas
2008	Balaka	Halord Alias	884	898.3	1126.4	97	2306.25	1	Farmers Check
2008	Balaka	Halord Alias	884	898.3	1126.4	97	4738.33	2	CA+Maize
2008	Balaka	Halord Alias	884	898.3	1126.4	97	3893.45	3	CA+Maize+cowpeas
2007	Balaka	Halord Alias	799	898.3	975.7	100	1700.34	1	Farmers Check
2007	Balaka	Halord Alias	799	898.3	975.7	100	3972.47	2	CA+Maize
2007	Balaka	Halord Alias	799	898.3	975.7	100	3628.71	3	CA+Maize+cowpeas
2006	Balaka	Halord Alias	943	898.3	1063.2	97	1134.62	1	Farmers Check
2006	Balaka	Halord Alias	943	898.3	1063.2	97	3388.89	2	CA+Maize
2006	Balaka	Halord Alias	943	898.3	1063.2	97	2979.55	3	CA+Maize+cowpeas
2009	Balaka	Kassim Masi	797	761.1	661	84	1579.25	1	Farmers Check
2009	Balaka	Kassim Masi	797	761.1	661	84	1802.47	2	CA+Maize
2009	Balaka	Kassim Masi	797	761.1	661	84	2639.27	3	CA+Maize+cowpeas
2008	Balaka	Kassim Masi	841	761.1	1126.4	100	968.61	1	Farmers Check
2008	Balaka	Kassim Masi	841	761.1	1126.4	100	1530.75	2	CA+Maize

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2008	Balaka	Kassim Masi	841	761.1	1126.4	100	2001.30	3	CA+Maize+cowpeas
2007	Balaka	Kassim Masi	734	761.1	975.7	100	3055.16	1	Farmers Check
2007	Balaka	Kassim Masi	734	761.1	975.7	100	5352.56	2	CA+Maize
2007	Balaka	Kassim Masi	734	761.1	975.7	100	4635.84	3	CA+Maize+cowpeas
2008	Balaka	Kingsley Kamwendo	884	898.3	1126.4	97	2691.54	1	Farmers Check
2008	Balaka	Kingsley Kamwendo	884	898.3	1126.4	97	7832.97	2	CA+Maize
2008	Balaka	Kingsley Kamwendo	884	898.3	1126.4	97	9086.24	3	CA+Maize+cowpeas
2006	Balaka	Kingsley Kamwendo	943	898.3	1063.2	97	2144.00	1	Farmers Check
2006	Balaka	Kingsley Kamwendo	943	898.3	1063.2	97	2580.22	2	CA+Maize
2006	Balaka	Kingsley Kamwendo	943	898.3	1063.2	97	1808.18	3	CA+Maize+cowpeas
2005	Balaka	Kingsley Kamwendo	727	898.3	526.5	100	2426.00	1	Farmers Check
2005	Balaka	Kingsley Kamwendo	727	898.3	526.5	100	4640.00	2	CA+Maize
2005	Balaka	Kingsley Kamwendo	727	898.3	526.5	100	7877.00	3	CA+Maize+cowpeas
2009	Balaka	Lughano Mwangonde	767	888.7	661	100	2935.57	1	Farmers Check
2009	Balaka	Lughano Mwangonde	767	888.7	661	100	3271.46	2	CA+Maize
2009	Balaka	Lughano Mwangonde	767	888.7	661	100	2628.98	3	CA+Maize+cowpeas
2008	Balaka	Lughano Mwangonde	884	888.7	1126.4	100	3388.66	1	Farmers Check
2008	Balaka	Lughano Mwangonde	884	888.7	1126.4	100	5891.23	2	CA+Maize
2008	Balaka	Lughano Mwangonde	884	888.7	1126.4	100	2828.57	3	CA+Maize+cowpeas
2007	Balaka	Lughano Mwangonde	799	888.7	975.7	100	3638.28	1	Farmers Check
2007	Balaka	Lughano Mwangonde	799	888.7	975.7	100	2753.71	2	CA+Maize
2007	Balaka	Lughano Mwangonde	799	888.7	975.7	100	2881.58	3	CA+Maize+cowpeas
2006	Balaka	Lughano Mwangonde	943	888.7	1063.2	97	8397.44	1	Farmers Check

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2006	Balaka	Lughano Mwangonde	943	888.7	1063.2	97	3203.64	2	CA+Maize
2006	Balaka	Lughano Mwangonde	943	888.7	1063.2	97	3291.32	3	CA+Maize+cowpeas
2005	Balaka	Lughano Mwangonde	727	888.7	526.5	100	3000.00	1	Farmers Check
2005	Balaka	Lughano Mwangonde	727	888.7	526.5	100	2200.00	2	CA+Maize
2005	Balaka	Lughano Mwangonde	727	888.7	526.5	100	3773.33	3	CA+Maize+cowpeas
2008	Balaka	S.Makuluni	870	841.4	1126.4	100	2260.02	1	Farmers Check
2008	Balaka	S.Makuluni	870	841.4	1126.4	100	5625.12	2	CA+Maize
2008	Balaka	S.Makuluni	870	841.4	1126.4	100	4345.47	3	CA+Maize+cowpeas
2007	Balaka	S.Makuluni	797	841.4	975.7	100	3007.04	1	Farmers Check
2007	Balaka	S.Makuluni	797	841.4	975.7	100	5981.08	2	CA+Maize
2007	Balaka	S.Makuluni	797	841.4	975.7	100	6347.99	3	CA+Maize+cowpeas
2007	Dowa	Amidu Saluyamvuka	846	632.8	1038.5	97	7460.61	1	Farmers Check
2007	Dowa	Amidu Saluyamvuka	846	632.8	1038.5	97	7343.02	2	CA+Maize
2007	Dowa	Amidu Saluyamvuka	846	632.8	1038.5	97	7291.24	3	CA+Maize+cowpeas
2008	Dowa	Chagamba Kafamveka	804	632.8	1041.6	100	7469.58	1	Farmers Check
2008	Dowa	Chagamba Kafamveka	804	632.8	1041.6	100	7685.29	2	CA+Maize
2008	Dowa	Chagamba Kafamveka	804	632.8	1041.6	100	6997.01	3	CA+Maize+cowpeas
2007	Dowa	Chagamba Kafamveka	846	632.8	1038.5	97	8916.32	1	Farmers Check
2007	Dowa	Chagamba Kafamveka	846	632.8	1038.5	97	7419.78	2	CA+Maize
2007	Dowa	Chagamba Kafamveka	846	632.8	1038.5	97	10035.04	3	CA+Maize+cowpeas
2008	Dowa	Daimon Mtondo	804	663.7	1041.6	100	5487.35	1	Farmers Check
2008	Dowa	Daimon Mtondo	804	663.7	1041.6	100	7379.06	2	CA+Maize
2008	Dowa	Daimon Mtondo	804	663.7	1041.6	100	6976.22	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2007	Dowa	Daimon Mtondo	846	663.7	1038.5	97	7172.29	1	Farmers Check
2007	Dowa	Daimon Mtondo	846	663.7	1038.5	97	8881.47	2	CA+Maize
2007	Dowa	Daimon Mtondo	846	663.7	1038.5	97	8490.45	3	CA+Maize+cowpeas
2009	Dowa	Henele Rabisoni	809	663.7	997.3	100	4808.28	1	Farmers Check
2009	Dowa	Henele Rabisoni	809	663.7	997.3	100	4941.89	2	CA+Maize
2009	Dowa	Henele Rabisoni	809	663.7	997.3	100	4971.39	3	CA+Maize+cowpeas
2007	Dowa	Henele Rabisoni	888	663.7	1038.5	97	9147.66	1	Farmers Check
2007	Dowa	Henele Rabisoni	888	663.7	1038.5	97	7635.10	2	CA+Maize
2007	Dowa	Henele Rabisoni	888	663.7	1038.5	97	8466.44	3	CA+Maize+cowpeas
2006	Dowa	Henele Rabisoni	854	663.7	947.6	100	3990.00	1	Farmers Check
2006	Dowa	Henele Rabisoni	854	663.7	947.6	100	3570.00	2	CA+Maize
2006	Dowa	Henele Rabisoni	854	663.7	947.6	100	4050.00	3	CA+Maize+cowpeas
2009	Dowa	Jenitala Zuze	731	663.7	997.3	99	4830.06	1	Farmers Check
2009	Dowa	Jenitala Zuze	731	663.7	997.3	99	4276.15	2	CA+Maize
2009	Dowa	Jenitala Zuze	731	663.7	997.3	99	4298.64	3	CA+Maize+cowpeas
2008	Dowa	Jenitala Zuze	804	663.7	1041.6	100	6682.83	1	Farmers Check
2008	Dowa	Jenitala Zuze	804	663.7	1041.6	100	7610.55	2	CA+Maize
2008	Dowa	Jenitala Zuze	804	663.7	1041.6	100	7117.23	3	CA+Maize+cowpeas
2007	Dowa	Jenitala Zuze	846	663.7	1038.5	97	6174.52	1	Farmers Check
2007	Dowa	Jenitala Zuze	846	663.7	1038.5	97	6134.04	2	CA+Maize
2007	Dowa	Jenitala Zuze	846	663.7	1038.5	97	5576.83	3	CA+Maize+cowpeas
2006	Dowa	Jenitala Zuze	858	663.7	947.6	100	5460.00	1	Farmers Check
2006	Dowa	Jenitala Zuze	858	663.7	947.6	100	4380.00	2	CA+Maize

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2006	Dowa	Jenitala Zuze	858	663.7	947.6	100	4880.00	3	CA+Maize+cowpeas
2009	Dowa	Kilioni Sikalioti	731	663.7	997.3	100	5210.29	1	Farmers Check
2009	Dowa	Kilioni Sikalioti	731	663.7	997.3	100	5750.80	2	CA+Maize
2009	Dowa	Kilioni Sikalioti	731	663.7	997.3	100	5852.54	3	CA+Maize+cowpeas
2007	Dowa	Kilioni Sikalioti	846	663.7	1038.5	97	8863.02	1	Farmers Check
2007	Dowa	Kilioni Sikalioti	846	663.7	1038.5	97	6440.02	2	CA+Maize
2007	Dowa	Kilioni Sikalioti	846	663.7	1038.5	97	8662.52	3	CA+Maize+cowpeas
2009	Dowa	Langiton Chipeni	731	663.7	997.3	99	4197.57	1	Farmers Check
2009	Dowa	Langiton Chipeni	731	663.7	997.3	99	4441.61	2	CA+Maize
2009	Dowa	Langiton Chipeni	731	663.7	997.3	99	5631.51	3	CA+Maize+cowpeas
2007	Dowa	Langiton Chipeni	846	663.7	1038.5	97	7973.32	1	Farmers Check
2007	Dowa	Langiton Chipeni	846	663.7	1038.5	97	8205.37	2	CA+Maize
2007	Dowa	Langiton Chipeni	846	663.7	1038.5	97	9811.85	3	CA+Maize+cowpeas
2007	Dowa	M. Chikhosi	888	663.7	1038.5	97	4427.04	1	Farmers Check
2007	Dowa	M. Chikhosi	888	663.7	1038.5	97	4834.86	2	CA+Maize
2007	Dowa	M. Chikhosi	888	663.7	1038.5	97	4512.95	3	CA+Maize+cowpeas
2009	Dowa	Majoni Lawrent	731	663.7	997.3	99	4231.23	1	Farmers Check
2009	Dowa	Majoni Lawrent	731	663.7	997.3	99	3704.40	2	CA+Maize
2009	Dowa	Majoni Lawrent	731	663.7	997.3	99	4089.56	3	CA+Maize+cowpeas
2007	Dowa	Majoni Lawrent	846	663.7	1038.5	97	5766.46	1	Farmers Check
2007	Dowa	Majoni Lawrent	846	663.7	1038.5	97	4410.99	2	CA+Maize
2007	Dowa	Majoni Lawrent	846	663.7	1038.5	97	4007.56	3	CA+Maize+cowpeas
2007	Dowa	Malizani Padzuwa	846	663.7	1038.5	100	9873.15	1	Farmers Check

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2007	Dowa	Malizani Padzuwa	846	663.7	1038.5	100	8071.38	2	CA+Maize
2007	Dowa	Malizani Padzuwa	846	663.7	1038.5	100	8913.44	3	CA+Maize+cowpeas
2008	Dowa	Njatani Manyozo	804	632.8	1041.6	100	3384.56	1	Farmers Check
2008	Dowa	Njatani Manyozo	804	632.8	1041.6	100	3250.23	2	CA+Maize
2008	Dowa	Njatani Manyozo	804	632.8	1041.6	100	3879.76	3	CA+Maize+cowpeas
2007	Dowa	Njatani Manyozo	846	632.8	1038.5	97	12093.76	1	Farmers Check
2007	Dowa	Njatani Manyozo	846	632.8	1038.5	97	6001.56	2	CA+Maize
2007	Dowa	Njatani Manyozo	846	632.8	1038.5	97	6387.07	3	CA+Maize+cowpeas
2008	Dowa	P. Chikhosi	804	663.7	1041.6	100	5997.74	1	Farmers Check
2008	Dowa	P. Chikhosi	804	663.7	1041.6	100	3834.88	2	CA+Maize
2008	Dowa	P. Chikhosi	804	663.7	1041.6	100	5091.41	3	CA+Maize+cowpeas
2007	Dowa	P. Chikhosi	846	663.7	1038.5	97	6840.58	1	Farmers Check
2007	Dowa	P. Chikhosi	846	663.7	1038.5	97	7252.29	2	CA+Maize
2007	Dowa	P. Chikhosi	846	663.7	1038.5	97	6769.42	3	CA+Maize+cowpeas
2006	Dowa	P. Chikhosi	858	663.7	947.6	100	3240.00	1	Farmers Check
2006	Dowa	P. Chikhosi	858	663.7	947.6	100	3100.00	2	CA+Maize
2006	Dowa	P. Chikhosi	858	663.7	947.6	100	4710.00	3	CA+Maize+cowpeas
2008	Dowa	Rolenti Kamawindo	804	663.7	1041.6	100	7430.99	1	Farmers Check
2008	Dowa	Rolenti Kamawindo	804	663.7	1041.6	100	7203.06	2	CA+Maize
2008	Dowa	Rolenti Kamawindo	804	663.7	1041.6	100	8468.27	3	CA+Maize+cowpeas
2007	Dowa	Rolenti Kamawindo	846	663.7	1038.5	97	8859.59	1	Farmers Check
2007	Dowa	Rolenti Kamawindo	846	663.7	1038.5	97	6381.50	2	CA+Maize
2007	Dowa	Rolenti Kamawindo	846	663.7	1038.5	97	7528.37	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2007	Dowa	Wilson Pitoni	888	663.7	1038.5	97	7932.99	1	Farmers Check
2007	Dowa	Wilson Pitoni	888	663.7	1038.5	97	7374.59	2	CA+Maize
2007	Dowa	Wilson Pitoni	888	663.7	1038.5	97	7474.07	3	CA+Maize+cowpeas
2006	Dowa	Wilson Pitoni	854	663.7	947.6	100	4430.00	1	Farmers Check
2006	Dowa	Wilson Pitoni	854	663.7	947.6	100	3490.00	2	CA+Maize
2006	Dowa	Wilson Pitoni	854	663.7	947.6	100	4830.00	3	CA+Maize+cowpeas
2009	Machinga	Amos Mathias	699	801.5	1053.9	88	1396.65	1	Farmers Check
2009	Machinga	Amos Mathias	699	801.5	1053.9	88	2643.67	2	CA+Maize
2009	Machinga	Amos Mathias	699	801.5	1053.9	88	2164.86	3	CA+Maize+cowpeas
2008	Machinga	Amos Mathias	838	801.5	1037.3	96	4648.16	1	Farmers Check
2008	Machinga	Amos Mathias	838	801.5	1037.3	96	6808.95	2	CA+Maize
2008	Machinga	Amos Mathias	838	801.5	1037.3	96	7715.64	3	CA+Maize+cowpeas
2007	Machinga	Amos Mathias	789	801.5	1211.5	100	1234.63	1	Farmers Check
2007	Machinga	Amos Mathias	789	801.5	1211.5	100	5586.52	2	CA+Maize
2007	Machinga	Amos Mathias	789	801.5	1211.5	100	5487.34	3	CA+Maize+cowpeas
2009	Machinga	Beyard Aufi	699	801.5	1053.9	88	933.04	1	Farmers Check
2009	Machinga	Beyard Aufi	699	801.5	1053.9	88	1890.94	2	CA+Maize
2009	Machinga	Beyard Aufi	699	801.5	1053.9	88	2759.46	3	CA+Maize+cowpeas
2008	Machinga	Beyard Aufi	838	801.5	1037.3	96	4264.35	1	Farmers Check
2008	Machinga	Beyard Aufi	838	801.5	1037.3	96	9355.72	2	CA+Maize
2008	Machinga	Beyard Aufi	838	801.5	1037.3	96	9958.94	3	CA+Maize+cowpeas
2007	Machinga	Beyard Aufi	789	801.5	1211.5	100	1334.79	1	Farmers Check
2007	Machinga	Beyard Aufi	789	801.5	1211.5	100	4182.20	2	CA+Maize

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2007	Machinga	Beyard Aufi	789	801.5	1211.5	100	4735.40	3	CA+Maize+cowpeas
2009	Machinga	Brayon Kajawo	699	801.5	1053.9	88	1177.68	1	Farmers Check
2009	Machinga	Brayon Kajawo	699	801.5	1053.9	88	2367.69	2	CA+Maize
2009	Machinga	Brayon Kajawo	699	801.5	1053.9	88	2682.30	3	CA+Maize+cowpeas
2008	Machinga	Brayon Kajawo	838	801.5	1037.3	96	3561.75	1	Farmers Check
2008	Machinga	Brayon Kajawo	838	801.5	1037.3	96	7205.17	2	CA+Maize
2008	Machinga	Brayon Kajawo	838	801.5	1037.3	96	7725.34	3	CA+Maize+cowpeas
2007	Machinga	Brayon Kajawo	789	801.5	1211.5	100	2473.07	1	Farmers Check
2007	Machinga	Brayon Kajawo	789	801.5	1211.5	100	4607.87	2	CA+Maize
2007	Machinga	Brayon Kajawo	789	801.5	1211.5	100	4539.47	3	CA+Maize+cowpeas
2009	Machinga	Edson Matika	699	801.5	1053.9	88	2031.40	1	Farmers Check
2009	Machinga	Edson Matika	699	801.5	1053.9	88	2102.35	2	CA+Maize
2009	Machinga	Edson Matika	699	801.5	1053.9	88	2489.05	3	CA+Maize+cowpeas
2008	Machinga	Edson Matika	838	801.5	1037.3	96	4660.68	1	Farmers Check
2008	Machinga	Edson Matika	838	801.5	1037.3	96	5785.23	2	CA+Maize
2008	Machinga	Edson Matika	838	801.5	1037.3	96	5785.32	3	CA+Maize+cowpeas
2007	Machinga	Edson Matika	789	801.5	1211.5	100	2641.30	1	Farmers Check
2007	Machinga	Edson Matika	789	801.5	1211.5	100	4469.36	2	CA+Maize
2007	Machinga	Edson Matika	789	801.5	1211.5	100	4963.90	3	CA+Maize+cowpeas
2009	Machinga	Esnat Shaibu	699	801.5	1053.9	88	1476.26	1	Farmers Check
2009	Machinga	Esnat Shaibu	699	801.5	1053.9	88	2633.01	2	CA+Maize
2009	Machinga	Esnat Shaibu	699	801.5	1053.9	88	2527.92	3	CA+Maize+cowpeas
2008	Machinga	Esnat Shaibu	838	801.5	1037.3	96	3460.10	1	Farmers Check

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2008	Machinga	Esnat Shaibu	838	801.5	1037.3	96	4718.28	2	CA+Maize
2008	Machinga	Esnat Shaibu	838	801.5	1037.3	96	5439.47	3	CA+Maize+cowpeas
2007	Machinga	Esnat Shaibu	789	801.5	1211.5	100	2080.01	1	Farmers Check
2007	Machinga	Esnat Shaibu	789	801.5	1211.5	100	5119.57	2	CA+Maize
2007	Machinga	Esnat Shaibu	789	801.5	1211.5	100	5514.85	3	CA+Maize+cowpeas
2009	Machinga	Stanley Ndege	699	801.5	1053.9	88	1633.83	1	Farmers Check
2009	Machinga	Stanley Ndege	699	801.5	1053.9	88	2103.43	2	CA+Maize
2009	Machinga	Stanley Ndege	699	801.5	1053.9	88	1894.91	3	CA+Maize+cowpeas
2008	Machinga	Stanley Ndege	838	801.5	1037.3	96	3384.02	1	Farmers Check
2008	Machinga	Stanley Ndege	838	801.5	1037.3	96	5269.65	2	CA+Maize
2008	Machinga	Stanley Ndege	838	801.5	1037.3	96	4655.82	3	CA+Maize+cowpeas
2009	Nkhotakota	Agness Mankhwazi	987	1512.5	859.5	100	7201.06	1	Farmers Check
2009	Nkhotakota	Agness Mankhwazi	987	1512.5	859.5	100	8681.58	2	CA+Maize
2009	Nkhotakota	Agness Mankhwazi	987	1512.5	859.5	100	5685.39	3	CA+Maize+cowpeas
2008	Nkhotakota	Agness Mankhwazi	878	1512.5	831.1	100	5339.80	1	Farmers Check
2008	Nkhotakota	Agness Mankhwazi	878	1512.5	831.1	100	4513.25	2	CA+Maize
2008	Nkhotakota	Agness Mankhwazi	878	1512.5	831.1	100	5200.16	3	CA+Maize+cowpeas
2007	Nkhotakota	Agness Mankhwazi	934	1512.5	837.1	97	4449.22	1	Farmers Check
2007	Nkhotakota	Agness Mankhwazi	934	1512.5	837.1	97	6155.67	2	CA+Maize
2007	Nkhotakota	Agness Mankhwazi	934	1512.5	837.1	97	5805.61	3	CA+Maize+cowpeas
2006	Nkhotakota	Agness Mankhwazi	789	1512.5	892.5	100	4500.00	1	Farmers Check
2006	Nkhotakota	Agness Mankhwazi	789	1512.5	892.5	100	4960.00	2	CA+Maize
2006	Nkhotakota	Agness Mankhwazi	789	1512.5	892.5	100	5547.00	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2008	Nkhotakota	D. Scot	878	1341.9	831.1	100	2110.96	1	Farmers Check
2008	Nkhotakota	D. Scot	878	1341.9	831.1	100	2488.44	2	CA+Maize
2008	Nkhotakota	D. Scot	878	1341.9	831.1	100	2217.71	3	CA+Maize+cowpeas
2007	Nkhotakota	D. Scot	934	1341.9	837.1	97	2257.16	1	Farmers Check
2007	Nkhotakota	D. Scot	934	1341.9	837.1	97	1900.25	2	CA+Maize
2007	Nkhotakota	D. Scot	934	1341.9	837.1	97	1779.16	3	CA+Maize+cowpeas
2006	Nkhotakota	D. Scot	789	1341.9	892.5	100	2805.00	1	Farmers Check
2006	Nkhotakota	D. Scot	789	1341.9	892.5	100	3360.00	2	CA+Maize
2006	Nkhotakota	D. Scot	789	1341.9	892.5	100	5000.00	3	CA+Maize+cowpeas
2008	Nkhotakota	E. CHIMBIYA	863	1517.3	831.1	100	5170.21	1	Farmers Check
2008	Nkhotakota	E. CHIMBIYA	863	1517.3	831.1	100	4428.68	2	CA+Maize
2008	Nkhotakota	E. CHIMBIYA	863	1517.3	831.1	100	3801.03	3	CA+Maize+cowpeas
2007	Nkhotakota	E. CHIMBIYA	944	1517.3	837.1	100	2181.26	1	Farmers Check
2007	Nkhotakota	E. CHIMBIYA	944	1517.3	837.1	100	3292.59	2	CA+Maize
2007	Nkhotakota	E. CHIMBIYA	944	1517.3	837.1	100	3162.25	3	CA+Maize+cowpeas
2006	Nkhotakota	E. CHIMBIYA	803	1517.3	892.5	100	4373.00	1	Farmers Check
2006	Nkhotakota	E. CHIMBIYA	803	1517.3	892.5	100	4000.00	2	CA+Maize
2006	Nkhotakota	E. CHIMBIYA	803	1517.3	892.5	100	4420.00	3	CA+Maize+cowpeas
2009	Nkhotakota	Ekisinala Azele	987	1517.3	859.5	100	4281.39	1	Farmers Check
2009	Nkhotakota	Ekisinala Azele	987	1517.3	859.5	100	7264.33	2	CA+Maize
2009	Nkhotakota	Ekisinala Azele	987	1517.3	859.5	100	3798.65	3	CA+Maize+cowpeas
2008	Nkhotakota	Ekisinala Azele	878	1517.3	831.1	100	3115.18	1	Farmers Check
2008	Nkhotakota	Ekisinala Azele	878	1517.3	831.1	100	3029.77	2	CA+Maize

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2008	Nkhotakota	Ekisinala Azele	878	1517.3	831.1	100	3936.22	3	CA+Maize+cowpeas
2007	Nkhotakota	Ekisinala Azele	934	1517.3	837.1	97	991.80	1	Farmers Check
2007	Nkhotakota	Ekisinala Azele	934	1517.3	837.1	97	3768.76	2	CA+Maize
2007	Nkhotakota	Ekisinala Azele	934	1517.3	837.1	97	2284.88	3	CA+Maize+cowpeas
2006	Nkhotakota	Ekisinala Azele	789	1517.3	892.5	100	4627.00	1	Farmers Check
2006	Nkhotakota	Ekisinala Azele	789	1517.3	892.5	100	4968.00	2	CA+Maize
2006	Nkhotakota	Ekisinala Azele	789	1517.3	892.5	100	5760.00	3	CA+Maize+cowpeas
2009	Nkhotakota	Gilbert Filimon	987	1517	859.5	100	6340.30	1	Farmers Check
2009	Nkhotakota	Gilbert Filimon	987	1517	859.5	100	6126.29	2	CA+Maize
2009	Nkhotakota	Gilbert Filimon	987	1517	859.5	100	7517.06	3	CA+Maize+cowpeas
2008	Nkhotakota	Gilbert Filimon	878	1517	831.1	100	4694.02	1	Farmers Check
2008	Nkhotakota	Gilbert Filimon	878	1517	831.1	100	3908.17	2	CA+Maize
2008	Nkhotakota	Gilbert Filimon	878	1517	831.1	100	3071.31	3	CA+Maize+cowpeas
2007	Nkhotakota	Gilbert Filimon	934	1517	837.1	97	974.43	1	Farmers Check
2007	Nkhotakota	Gilbert Filimon	934	1517	837.1	97	1931.31	2	CA+Maize
2007	Nkhotakota	Gilbert Filimon	934	1517	837.1	97	1974.96	3	CA+Maize+cowpeas
2006	Nkhotakota	Gilbert Filimon	789	1517	892.5	100	2560.00	1	Farmers Check
2006	Nkhotakota	Gilbert Filimon	789	1517	892.5	100	3627.00	2	CA+Maize
2006	Nkhotakota	Gilbert Filimon	789	1517	892.5	100	4267.00	3	CA+Maize+cowpeas
2009	Nkhotakota	Grace Malaitcha	1080	1517	859.5	97	0.00	1	Farmers Check
2009	Nkhotakota	Grace Malaitcha	1080	1517	859.5	97	6710.08	2	CA+Maize
2009	Nkhotakota	Grace Malaitcha	1080	1517	859.5	97	6326.94	3	CA+Maize+cowpeas
2008	Nkhotakota	Grace Malaitcha	863	1517	831.1	100	7493.53	1	Farmers Check

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2008	Nkhotakota	Grace Malaitcha	863	1517	831.1	100	7965.19	2	CA+Maize
2008	Nkhotakota	Grace Malaitcha	863	1517	831.1	100	6315.45	3	CA+Maize+cowpeas
2009	Nkhotakota	Jelimoti Sikelo	987	1341.9	859.5	100	5419.81	1	Farmers Check
2009	Nkhotakota	Jelimoti Sikelo	987	1341.9	859.5	100	5676.01	2	CA+Maize
2009	Nkhotakota	Jelimoti Sikelo	987	1341.9	859.5	100	6800.20	3	CA+Maize+cowpeas
2008	Nkhotakota	Jelimoti Sikelo	878	1341.9	831.1	100	4555.96	1	Farmers Check
2008	Nkhotakota	Jelimoti Sikelo	878	1341.9	831.1	100	5055.64	2	CA+Maize
2008	Nkhotakota	Jelimoti Sikelo	878	1341.9	831.1	100	5312.84	3	CA+Maize+cowpeas
2007	Nkhotakota	Jelimoti Sikelo	934	1341.9	837.1	97	2556.86	1	Farmers Check
2007	Nkhotakota	Jelimoti Sikelo	934	1341.9	837.1	97	3798.69	2	CA+Maize
2007	Nkhotakota	Jelimoti Sikelo	934	1341.9	837.1	97	5276.00	3	CA+Maize+cowpeas
2006	Nkhotakota	Jelimoti Sikelo	789	1341.9	892.5	100	2060.00	1	Farmers Check
2006	Nkhotakota	Jelimoti Sikelo	789	1341.9	892.5	100	5120.00	2	CA+Maize
2006	Nkhotakota	Jelimoti Sikelo	789	1341.9	892.5	100	6660.00	3	CA+Maize+cowpeas
2009	Nkhotakota	Medson Chitsulo	987	1512.5	859.5	100	7666.76	1	Farmers Check
2009	Nkhotakota	Medson Chitsulo	987	1512.5	859.5	100	6979.73	2	CA+Maize
2009	Nkhotakota	Medson Chitsulo	987	1512.5	859.5	100	8827.86	3	CA+Maize+cowpeas
2008	Nkhotakota	Medson Chitsulo	878	1512.5	831.1	100	3652.44	1	Farmers Check
2008	Nkhotakota	Medson Chitsulo	878	1512.5	831.1	100	4314.44	2	CA+Maize
2008	Nkhotakota	Medson Chitsulo	878	1512.5	831.1	100	3922.22	3	CA+Maize+cowpeas
2007	Nkhotakota	Medson Chitsulo	934	1512.5	837.1	97	4374.04	1	Farmers Check
2007	Nkhotakota	Medson Chitsulo	934	1512.5	837.1	97	5102.92	2	CA+Maize
2007	Nkhotakota	Medson Chitsulo	934	1512.5	837.1	97	4867.30	3	CA+Maize+cowpeas

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2009	Nkhotakota	Samuel Maxwell Phiri	987	1341.9	859.5	100	2676.32	1	Farmers Check
2009	Nkhotakota	Samuel Maxwell Phiri	987	1341.9	859.5	100	3122.90	2	CA+Maize
2009	Nkhotakota	Samuel Maxwell Phiri	987	1341.9	859.5	100	3492.91	3	CA+Maize+cowpeas
2006	Nkhotakota	Samuel Maxwell Phiri	789	1341.9	892.5	100	2210.00	1	Farmers Check
2006	Nkhotakota	Samuel Maxwell Phiri	789	1341.9	892.5	100	7650.00	2	CA+Maize
2006	Nkhotakota	Samuel Maxwell Phiri	789	1341.9	892.5	100	6480.00	3	CA+Maize+cowpeas
2009	Salima	Christopher Helema	847	1166.5	821.8	100	6648.05	1	Farmers Check
2009	Salima	Christopher Helema	847	1166.5	821.8	100	7405.51	2	CA+Maize
2009	Salima	Christopher Helema	847	1166.5	821.8	100	6733.45	3	CA+Maize+cowpeas
2009	Salima	Dryson Anderson	847	1166.5	821.8	100	6962.18	1	Farmers Check
2009	Salima	Dryson Anderson	847	1166.5	821.8	100	9372.27	2	CA+Maize
2009	Salima	Dryson Anderson	847	1166.5	821.8	100	5206.30	3	CA+Maize+cowpeas
2009	Salima	Edina Kabwabwa	905	1166.5	821.8	100	5672.98	1	Farmers Check
2009	Salima	Edina Kabwabwa	905	1166.5	821.8	100	7712.21	2	CA+Maize
2009	Salima	Edina Kabwabwa	905	1166.5	821.8	100	5485.16	3	CA+Maize+cowpeas
2009	Salima	Evelyne Chingwalu	847	1166.5	821.8	100	6982.39	1	Farmers Check
2009	Salima	Evelyne Chingwalu	847	1166.5	821.8	100	7193.78	2	CA+Maize
2009	Salima	Evelyne Chingwalu	847	1166.5	821.8	100	5563.01	3	CA+Maize+cowpeas
2009	Salima	Jalibesi Mphonongo	847	1166.5	821.8	100	3798.15	1	Farmers Check
2009	Salima	Jalibesi Mphonongo	847	1166.5	821.8	100	6556.75	2	CA+Maize
2009	Salima	Jalibesi Mphonongo	847	1166.5	821.8	100	4853.02	3	CA+Maize+cowpeas
2009	Salima	William Nthala	847	1166.5	821.8	100	6611.10	1	Farmers Check
2009	Salima	William Nthala	847	1166.5	821.8	100	5952.87	2	CA+Maize

Harvest Year	District	Farmer	NOAA Rainfall estimates	Long term average rainfall	Rain gauge rainfall	WRSI	Grain yield (kg/ha)	Plot No.	Plot Treatment
2009	Salima	William Nthala	847	1166.5	821.8	100	6943.25	3	CA+Maize+cowpeas
2008	Zomba	Ivy Kalosi	768	836.9	1285.3	86	2609.53	1	Farmers Check
2008	Zomba	Ivy Kalosi	768	836.9	1285.3	86	1890.40	2	CA+Maize
2008	Zomba	Ivy Kalosi	768	836.9	1285.3	86	1882.78	3	CA+Maize+cowpeas
2008	Zomba	Leonard Malikebu	768	836.9	1285.3	86	5320.48	1	Farmers Check
2008	Zomba	Leonard Malikebu	768	836.9	1285.3	86	6651.32	2	CA+Maize
2008	Zomba	Leonard Malikebu	768	836.9	1285.3	86	6794.85	3	CA+Maize+cowpeas
2008	Zomba	Patuma Wilson	699	768	1285.3	87	6853.61	1	Farmers Check
2008	Zomba	Patuma Wilson	699	768	1285.3	87	9365.43	2	CA+Maize
2008	Zomba	Patuma Wilson	699	768	1285.3	87	7453.10	3	CA+Maize+cowpeas

ANNEX 3: Annual Rainfall (mm/a), WRSI (%), Grain yield (kg/ha) at EPA level

Harvest Year	District	EPA Name	Average Grain Yield (Kg/ha)	WRSI	Predicted Grain Yield (%)	Actual Grain Yield (%)	Annual Rainfall (mm)
1985	Balaka	Bazale	1000	96	90 - 100	20	1065.1
1991	Balaka	Bazale	23	59	20-Oct	0.5	933.8
1992	Balaka	Bazale	24	99	90 - 100	0.5	414.7
1993	Balaka	Bazale	3120	98	90 - 100	62.4	786.9
1995	Balaka	Bazale	2200	93	50 - 90	44	801
1996	Balaka	Bazale	18	88	50 - 90	0.4	827
1997	Balaka	Bazale	137	100	>100	2.7	1578.6
1998	Balaka	Bazale	135	97	90 - 100	2.7	765.6
1999	Balaka	Bazale	386	96	90 - 100	7.7	1019
2000	Balaka	Bazale	3389	82	50 - 90	67.8	822.6
2001	Balaka	Bazale	1994	91	50 - 90	39.9	2827.6
2002	Balaka	Bazale	1274	91	50 - 90	25.5	1459.9
2003	Balaka	Bazale	236	90	50 - 90	4.7	1481.3
2005	Balaka	Bazale	719	100	>100	14.4	526.5
2006	Balaka	Bazale	2244	82	50 - 90	44.9	1063.2
2007	Balaka	Bazale	2374	95	90 - 100	47.5	975.5
2008	Balaka	Bazale	1732	99	90 - 100	34.6	1126.4
2009	Balaka	Bazale	2575	89	50 - 90	51.5	661
1990	Dowa	Mvera	2980	94	50 - 90	59.6	849
1991	Dowa	Mvera	36	85	50 - 90	0.7	667.4
1992	Dowa	Mvera	9	100	>100	0.2	585.6
1993	Dowa	Mvera	3670	99	90 - 100	73.4	910.8
1994	Dowa	Mvera	1912	99	90 - 100	38.2	567.5
1995	Dowa	Mvera	286	97	90 - 100	5.7	517.1
1996	Dowa	Mvera	272	97	90 - 100	5.4	996.3
1997	Dowa	Mvera	220	91	50 - 90	4.4	821.3
1998	Dowa	Mvera	1798	97	90 - 100	36	1275
1999	Dowa	Mvera	1979	100	>100	39.6	977.9
2000	Dowa	Mvera	2353	94	50 - 90	47.1	719.8
2001	Dowa	Mvera	1973	83	50 - 90	39.5	1184.2
2002	Dowa	Mvera	1593	90	50 - 90	31.9	800
2003	Dowa	Mvera	1968	96	90 - 100	39.4	1446.3
2005	Dowa	Mvera	113	96	90 - 100	2.3	750.6

Harvest Year	District	EPA Name	Average Grain Yield (Kg/ha)	WRSI	Predicted Grain Yield (%)	Actual Grain Yield (%)	Annual Rainfall (mm)
2006	Dowa	Mvera	2333	97	90 - 100	46.7	754.6
2007	Dowa	Mvera	284	94	50 - 90	5.7	998.7
2008	Dowa	Mvera	2155	100	>100	43.1	1030.6
2009	Dowa	Mvera	3743	100	>100	74.9	821.8
1992	Machinga	Ntubwi	98	99	90 - 100	2	888.9
1993	Machinga	Ntubwi	2630	83	50 - 90	52.6	1331.3
1995	Machinga	Ntubwi	2	90	50 - 90	0	1450.3
1996	Machinga	Ntubwi	164	91	50 - 90	3.3	1483.4
1997	Machinga	Ntubwi	18	100	>100	0.4	1877.2
1998	Machinga	Ntubwi	173	100	>100	3.5	1445
1999	Machinga	Ntubwi	2667	99	90 - 100	53.3	1208.1
2000	Machinga	Ntubwi	26	95	90 - 100	0.5	770.3
2001	Machinga	Ntubwi	1972	93	50 - 90	39.4	747.3
2002	Machinga	Ntubwi	184	100	>100	3.7	1129.5
2003	Machinga	Ntubwi	237	84	50 - 90	4.7	1275.8
2005	Machinga	Ntubwi	464	96	90 - 100	9.3	798.1
2006	Machinga	Ntubwi	2349	82	50 - 90	47	1561.6
2007	Machinga	Ntubwi	2816	100	>100	56.3	648.2
2008	Machinga	Ntubwi	1881	100	>100	37.6	1038.5
2009	Machinga	Ntubwi	3178	76	20 - 50	63.6	1041.6
1988	Nkhotakota	Mwansambo	13	97	90 - 100	0.3	730.1
1990	Nkhotakota	Mwansambo	1916	92	50 - 90	38.3	1165.9
1991	Nkhotakota	Mwansambo	35	77	20 - 50	0.7	1021.6
1992	Nkhotakota	Mwansambo	18	93	50 - 90	0.4	1009.7
1993	Nkhotakota	Mwansambo	365	100	>100	7.3	758.5
1996	Nkhotakota	Mwansambo	33	100	>100	0.7	1267.9
1997	Nkhotakota	Mwansambo	2592	91	50 - 90	51.8	1723.9
1998	Nkhotakota	Mwansambo	296	93	50 - 90	5.9	1208.2
1999	Nkhotakota	Mwansambo	3588	99	90 - 100	71.8	1414.8
2000	Nkhotakota	Mwansambo	3540	91	50 - 90	70.8	1009.4
2001	Nkhotakota	Mwansambo	2239	94	50 - 90	44.8	1225.1
2002	Nkhotakota	Mwansambo	2123	99	90 - 100	42.5	1687.8
2003	Nkhotakota	Mwansambo	1783	93	50 - 90	35.7	909.5
2005	Nkhotakota	Mwansambo	16	97	90 - 100	0.3	1432.9

Harvest Year	District	EPA Name	Average Grain Yield (Kg/ha)	WRSI	Predicted Grain Yield (%)	Actual Grain Yield (%)	Annual Rainfall (mm)
2006	Nkhotakota	Mwansambo	2656	97	90 - 100	53.1	1301.5
2007	Nkhotakota	Mwansambo	225	88	50 - 90	4.5	1314.5
2008	Nkhotakota	Mwansambo	272	93	50 - 90	5.4	1901.9
2009	Nkhotakota	Mwansambo	369	97	90 - 100	7.4	1691.8
1988	Nkhotakota	Zidyana	12	97	90 - 100	0.2	1137.6
1989	Nkhotakota	Zidyana	32	98	90 - 100	0.6	701.5
1990	Nkhotakota	Zidyana	1371	92	50 - 90	27.4	1471.8
1991	Nkhotakota	Zidyana	25	77	20 - 50	0.5	1554.8
1992	Nkhotakota	Zidyana	95	93	50 - 90	1.9	649.5
1993	Nkhotakota	Zidyana	2437	100	>100	48.7	722.9
1996	Nkhotakota	Zidyana	2276	100	>100	45.5	1785.1
1997	Nkhotakota	Zidyana	2350	91	50 - 90	47	1285.3
1998	Nkhotakota	Zidyana	1814	93	50 - 90	36.3	1211.3
1999	Nkhotakota	Zidyana	3277	99	90 - 100	65.5	1324.4
2000	Nkhotakota	Zidyana	2814	91	50 - 90	56.3	2146.4
2001	Nkhotakota	Zidyana	1458	94	50 - 90	29.2	1364.1
2002	Nkhotakota	Zidyana	2123	99	90 - 100	42.5	1271.9
2003	Nkhotakota	Zidyana	1783	93	50 - 90	35.7	1702.5
2005	Nkhotakota	Zidyana	113	97	90 - 100	2.3	1214.4
2006	Nkhotakota	Zidyana	2351	97	90 - 100	47	1374.3
2007	Nkhotakota	Zidyana	2259	88	50 - 90	45.2	1502.8
2008	Nkhotakota	Zidyana	257	93	50 - 90	5.1	1211.3
2009	Nkhotakota	Zidyana	3935	97	90 - 100	78.7	1414.8
1986	Salima	Chinguluwe	31	94	50 - 90	0.6	1324.4
1987	Salima	Chinguluwe	262	88	50 - 90	5.2	1009.4
1988	Salima	Chinguluwe	3	91	50 - 90	0.1	2146.4
1989	Salima	Chinguluwe	3	97	90 - 100	0.1	1225.1
1990	Salima	Chinguluwe	25	83	50 - 90	0.5	1364.1
1991	Salima	Chinguluwe	3	83	50 - 90	0.1	1687.8
1992	Salima	Chinguluwe	7	93	50 - 90	0.1	1271.9
1993	Salima	Chinguluwe	2748	58	20-Oct	55	909.5
1994	Salima	Chinguluwe	569	75	20 - 50	11.4	1702.5
1996	Salima	Chinguluwe	2300	100	>100	46	1432.9
1997	Salima	Chinguluwe	2155	94	50 - 90	43.1	1214.4

Harvest Year	District	EPA Name	Average Grain Yield (Kg/ha)	WRSI	Predicted Grain Yield (%)	Actual Grain Yield (%)	Annual Rainfall (mm)
1998	Salima	Chinguluwe	1962	97	90 - 100	39.2	1301.5
1999	Salima	Chinguluwe	397	96	90 - 100	7.9	1374.3
2000	Salima	Chinguluwe	361	94	50 - 90	7.2	1314.5
2001	Salima	Chinguluwe	2618	91	50 - 90	52.4	1502.8
2002	Salima	Chinguluwe	1979	91	50 - 90	39.6	1901.9
2003	Salima	Chinguluwe	275	100	>100	5.5	1185
2005	Salima	Chinguluwe	364	91	50 - 90	7.3	1148.6
2007	Salima	Chinguluwe	2693	97	90 - 100	53.9	1623.6
2008	Salima	Chinguluwe	2299	86	50 - 90	46	1387.3
2009	Salima	Chinguluwe	3263	96	90 - 100	65.3	1125.2
1990	Zomba	Malosa	2529	97	90 - 100	50.6	981.1
1991	Zomba	Malosa	35	74	20 - 50	0.7	991.2
1992	Zomba	Malosa	2	97	90 - 100	0	1558.9
1993	Zomba	Malosa	365	85	50 - 90	7.3	1037
1995	Zomba	Malosa	281	94	50 - 90	5.6	1177.4
1996	Zomba	Malosa	3248	91	50 - 90	65	984.3
1997	Zomba	Malosa	24	100	>100	0.5	1582.5
1998	Zomba	Malosa	213	91	50 - 90	4.3	1113.4
1999	Zomba	Malosa	2628	76	20 - 50	52.6	1361.5
2000	Zomba	Malosa	2441	35	<10	48.8	670.6
2001	Zomba	Malosa	154	88	50 - 90	3.1	661.4
2002	Zomba	Malosa	184	75	20 - 50	3.7	429.6
2003	Zomba	Malosa	237	87	50 - 90	4.7	892.9
2005	Zomba	Malosa	1821	90	50 - 90	36.4	803.9
2006	Zomba	Malosa	219	91	50 - 90	4.4	1051.7
2007	Zomba	Malosa	2974	91	50 - 90	59.5	876.1
2008	Zomba	Malosa	2541	100	>100	50.8	947.6
2009	Zomba	Malosa	3625	97	90 - 100	72.5	997.3