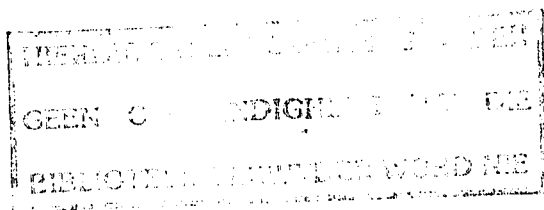
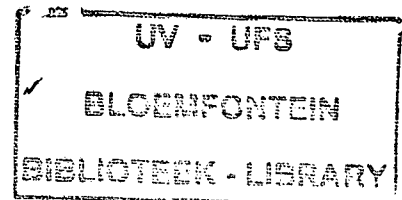


6154 596 39



University Free State



34300004297002

Universiteit Vrystaat

Universiteit van die
Vrystaat
BLOEMFONTEIN

21 SEP 2009

UV SACOL BIBLIOTHEK

**WATER AND NITROGEN MANAGEMENT
FOR RISK MITIGATION
IN SEMI-ARID CROPPING SYSTEMS**

by

WALTER T. MUPANGWA

A dissertation submitted
in accordance with
the requirement for the degree of

Doctor of Philosophy in Agrometeorology/Soil Science

In the Faculty of Natural and Agricultural Sciences
Department of Soil, Crop and Climate Sciences
University of the Free State

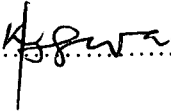
Supervisor: Prof. Sue Walker
Co-Supervisor: Dr. S.J. Twomlow

Bloemfontein

November 2008

DECLARATION

I declare that the dissertation hereby submitted by me for the PhD degree in Agrometeorology/Soil Science at the Faculty of Natural and Agricultural Sciences, University of the Free State, is my own independent work and has not been submitted by me at another university. I cede the copyright of the dissertation in favour of the University of the Free State.

Signature: 

Date: 13/2/09

ACKNOWLEDGEMENTS

'For with God nothing shall be impossible – Luke 1: 37'. I thank the Living God for taking me this far. I am grateful to WaterNet for funding my study through the CGIAR Challenge Programme on Water and Food Project (PN 17) 'Integrated Water Resources Management for Improved Rural Livelihoods: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water Scarce Limpopo Basin'.

To Professor Sue Walker and Dr. Stephen J. Twomlow who guided me in this study, may the Living God richly bless you. You endured the heat and rough roads of Gwanda and Insiza districts so that I can have a better future. I would also like to thank the fatherly Dr. John P. Dimes for assisting me during the modeling exercise. To my father, Peter Claver, thank you for riding the bicycle for all those years so that I could go to school. To my mother, Lilian Otilia, thank you for waking up early every morning and preparing breakfast and packed lunch during my school days. To my wife Terry and the girls, Mufaro and Munashe, thank you for enduring the long days when I was in the field, in the office at Matopos and in South Africa.

I owe special thank you to Sifiso'Gogo' Ncube, Ronelle and Rida for putting together all the logistics in order, you made my life easy. I am grateful to Gertrude Mpofu, Beckimpilo Ncube and Thulani Ndlovu for assisting me during the years of carrying out my experiments. To Dr. Andre van Rooyen and Prof. C.C. du Preez, I say thank you for the words of encouragement during the process of me getting this far.

Abstract

WATER AND NITROGEN MANAGEMENT FOR RISK MITIGATION IN SEMI-ARID CROPPING SYSTEMS

By

WALTER T. MUPANGWA

PhD Agrometeorology, University of the Free State, Bloemfontein

November 2008

This study was conducted with three main objectives which were firstly to characterize the smallholder farming system of semi-arid southern Zimbabwe and its rainfall pattern. The second objective was to quantify the crop yield and soil water benefits derived from *in situ* (single and double ploughing, ripping and planting basins) and inter-field (dead level contours and infiltration pits) soil water management techniques in southern Zimbabwe using field trials established on the farmers' fields. The on-farm study also explored the effect of combining *in situ* soil water management technologies (single and double ploughing, ripping and planting basins) and nitrogen fertilizer (0, 10 and 20 kgNha⁻¹) application on crop yield under semi-arid conditions. An on-station experiment was established to assess the effect of combining *in situ* soil water management techniques (single ploughing, ripping and planting basins) and mulching (0, 0.5, 1, 2, 4, 8 and 10 tha⁻¹) on maize, cowpea and sorghum yields, and soil water dynamics. The third objective was the evaluation of tillage systems on the farmers' fields over three growing seasons (2005/06, 2006/07 and 2007/08). The smallholder farmers appraised the tillage systems at the end of the last growing season of the study. Simulation modeling was then used to assess the long term effect of using the basin tillage system over a 69 year period.

The daily rainfall data was collected from five meteorological stations located in the Mzingwane catchment of the Limpopo basin. The analysis revealed that neither the total annual rainfall, based on the July-June calendar, nor the start nor end of growing season has changed significantly over the past 50-74 year period in southern Zimbabwe. The analysis indicated that the length of the growing season decreases along the Bulawayo to Beitbridge transect. The growing season starts during the first eight days of December at all stations except at Filabusi where the season starts during the last week of November. The number of wet days per growing season has also not changed along the Bulawayo to Beitbridge transect. There are better chances of getting rainfall during the January-March period compared to the first half of the growing season.

Our study revealed that there were no *in situ* soil water management techniques practiced by smallholder farmers in either Gwanda or Insiza districts during 2006. In Insiza district, the graded contours were the only structures constructed between fields while in Gwanda the dead level contours and infiltration pits were found on most farms particularly in wards 17 and 18. The dead level contours were being promoted by a Non-Governmental Organization (NGO) called Practical Action. Smallholder farmers in Insiza district used both manure and inorganic fertilizer as soil fertility amendments. However, in Gwanda district the majority of smallholder farmers used neither manure nor inorganic fertilizer for fear of crop burn. Farmers who used manure and fertilizer in Gwanda district had been exposed to how much manure and fertilizer is applied in semi-arid areas through interaction with agriculture extension officers and researchers. However, there is need for

wider promotion of training and demonstrations on soil water and fertility management in the semi-arid smallholder farming areas.

The on-farm experimentation assessed the effect of integrating soil water and nitrogen management under smallholder farming conditions. The study assessed the effect of single and double conventional ploughing, ripping and planting basins combined with nitrogen fertilizer on maize yields, surface runoff and soil water dynamics. Results of the on-farm experimentation showed that the double conventional ploughing combined with nitrogen fertilizer outperformed the other three tillage systems regardless of the rainfall pattern in Insiza and Gwanda districts. Nitrogen fertilizer increased maize yields and water use efficiency in each season regardless of the tillage system used under smallholder farming conditions. The planting basin system had higher maize crop establishment at most farms during the period of experimentation.

The on-station experiment showed that mulching had a significant influence on maize grain production across the three tillage systems in a season with below average rainfall. There were no significant maize yield differences across the three tillage systems tested at the on-station experimental site. Delayed planting in the conventional system resulted in reduced cowpea yields in a season with below average rainfall. Planting basin system gave lower sorghum yield as a result of reduced plant stand which was caused by rodent attack that was experienced at crop establishment stage. The on-station experiment indicated that sorghum and cowpea can be grown at the 0.9 m x 0.6 m spacing of the basin system without significantly reducing yield compared to the conventional system.

The soil water dynamics were similar under single and double ploughing, ripper and basin tillage systems. The on-station experiment also showed similar soil water dynamics in the conventional, ripper and basin systems under mulched conditions at Matopos (clay soil) and Lucydale (sandy soil). The basin system had more soil water during the November-December period when the growing seasons started. Surface runoff measurements indicated that planting basins significantly reduce surface runoff water losses from cropped or uncropped field. However, the reduced surface runoff and higher initial soil water content was not translated into higher yields under the basin tillage system compared to the other tillage systems.

The study on the soil water contribution of dead level contours and infiltration pits indicated that these inter-field structures have no significant effect on soil profile water content in seasons with below average rainfall. During seasons that receive daily rainfall events of more than 40 mm, the dead level contours and infiltration pits collect more rainwater than the dead level contour only. Lateral soil water movement occurred after rainfall events of 60-70 mm particularly downslope of the contour with significant changes in soil water being observed at 3 m from the contour. The dead level contours and infiltration pits supplied soil water to the 0.25-0.45 m layers of the 0.6 m profile measured in this study.

The evaluation of the *in situ* tillage systems by smallholder farmers revealed that labour demand and crop yields are major factors considered by smallholder farmers in semi-arid southern Zimbabwe when selecting a technology for adoption. The majority of the

farmers achieved the highest yields under the double ploughing system, hence they ranked it as the most appropriate tillage system to use under their conditions. Availability of cereal and legume seed is one of the major challenges being faced by all households sampled in Gwanda and Insiza districts during the period of our study. The long term assessment of the basin system through simulation modeling revealed that basins give only marginal maize yield benefits over the conventional system regardless of the nitrogen level used. The long term simulation also indicated that crop failures can be experienced in both conventional and basin systems due largely to uneven distribution of rain events through the growing season.

Uittreksel

WATER- EN STIKSTOFBESTUUR VIR RISIKO-VERMINDERING IN SEMI-ARIEDE GEWASSISTEME

deur

WALTER T. MUPANGWA

PhD Landbouweerkunde/Grondkunde, Universiteit van die Vrystaat, Bloemfontein

November 2008

Hierdie studie is uitgevoer met drie doelwitte in gedagte. Die eerste daarvan is die karakterisering van die kleinhoewe boerderysisteem en reënvalpatroon van semi-ariëde suidelike Zimbabwe. Die tweede doelstelling is om die gewasopbrengs- en grondwatervoordele wat ontstaan het uit *in situ* (enkel en dubbel ploeg, skeurploeg en plantbakkies) en tussenlandgrondwaterbestuur (waterpasgelyke kontoere en infiltrasiepitte) in suidelike Zimbabwe, te kwantifiseer, deur gebruik van veldproewe gevestig op plaaslanderye. Verder is die effek van samevatting van *in situ* grondwaterbestuurtegnologieë (enkel en dubbel ploeg, skeurploeg en plantbakkies) en stikstofbemestingtoediening (0, 10 en 20 kgNha⁻¹) op gewasopbrengs onder semi-ariëde toestande, ondersoek. 'n Eksperiment by die stasie is opgestel om die effek van kombinerings van *in situ* grondwaterbestuurtegnieke (enkel ploeg, skeurploeg en plantbakkies) en deklaag (0, 0.5, 1, 2, 4, 8 en 10 t ha⁻¹) op mielies, akkerboon en sorghum opbrengste, asook grondwaterdinamika, te assesser. Die derde doelstelling is die evaluering van tegnologieë getoets op boerelanderye oor drie groeiseisoene (2005/06, 2006/07 en 2007/2008). Die grondbewerkingsisteme is deur die kleinhoeweboere teen die eiende van die laaste groeiseisoen van die studie ge-evalueer. Simulasiemodelle is daarna gebruik om die langtermyneffekte van gebruik van bakkiegrondbewerkingsisteem oor 'n 69 jaar periode te evalueer.

Die daaglikse reënvaldata is vanaf meteorologiese stasies geleë in die Mzingwane opvanggebied van die groter Limpopo-opvanggebied, versamel. Die analises het getoon dat beide die totale jaarlikse reënval gebasseer op die Julie-Junie almanak, en die begin of einde van die groeiseisoen ewemin noemenswaardig verander het oor die 50-74 jarige periode in suidelike Zimbabwe. Die analise het wel getoon dat die lengte van die groeiseisoen verminder het langs die Bulawayo tot Beitbrugdeursnit. Die groeiseisoen begin gedurende die eerste agt dae van Desember by alle stasies behalwe by Filabusi waar die seisoen gedurende die laaste week van November begin. Die aantal nat dae per groeiseisoen het ook nie verander langs die Bulawayo tot Beitbrugdeursnit nie. Die kans is goed dat reënval gedurende Januarie-Maart periodes ontvang sal word vergeleke met die eerste helfte van die groeiseisoen.

Ons bevindinge het gewys dat daar geen *in situ* grondwaterbestuurstechnieke beoefen is deur kleinboere in beide die Gwanda en Insiza distrikte gedurende 2006 nie. In die Insiza distrik, is gegradeerde kontoure die enigste stukture opgerig tussende landerye terwyl in Gwanda is waterpasgelyke kontoure en infiltrasiepitte op meeste plase, veral in wyke 17 en 18 gevind. Waterpasgelyke kontoure word tans bevorder deur 'n Nie-Regeringsorganisasie of "Non-Governmental Organization" (NGO) genoem "Practical Action". Kleinboere in Insiza distrik gebruik beide mis asook anorganiese bemesting as grondbemestingswysigings. Die meerderheid kleinboere in Gwanda distrik gebruik egter nóg mis nóg anorganiese bemesting omrede gewasbrand ("cropburn") gevrees word. Boere wat wel mis en bemesting in Gwanda distrik gebruik,

is deur interaksie met landboukundige offisiere en navorsers touwys gemaak aangaande toedieningshoeveelhede van mis en bemesting in semi-ariëde gebiede. Daar is nogtans 'n behoefte aan nog meer bevordering van opleiding en demonstrasies van grondwater en fertiliteitsbestuur in die semi-ariëde kleinhoeweboerdery gebiede.

Die proewe uitgevoer op die plase het die effek van grondwater en stikstofbestuur onder kleinhoewe plaastoestande ge-assesseer. Die studie het die effek van enkel en dubbel konvensionele ploeg, skeurploeg en plantbakkies gekombineer met stikstofbemesting op mielieopbrengs, oppervlakaflowp en grondwaterdinamika, ge-assesseer. Die resultate het gewys dat die dubbel konvensionele ploeg gekombineer met stikstofbemesting die ander drie grondbewerkingsisteme oortref, ongeag die reënvalpatroon in die Insiza en Gwanda distrikte. Die studie het ook gewys dat die stikstofbemesting mielieopbrengste in elke seisoen verhoog het, ongeag die grondbewerkingsstelsel gebruik onder kleinhoeweboerdery toestande. Die plantbakkiesistelsel het hoër mieliegewasvestiging op meeste plase tydens die proeftydperk opgelewer.

Die proef by die stasie het getoon dat die deklaag 'n noemenswaardige invloed op mieliegraanproduksie vir al drie grondbewerkingsisteme in 'n seisoen met onder gemiddelde reënval getoets, gehad het. Daar is geen noemenswaardige mielieopbrengsverskille tussen die drie grondbewerkingsisteme getoets nie. Laat aanplanting by die konvensionele stelsel het gelei tot afname in akkerboon opbrengste binne 'n seisoen met onder gemiddelde reënval. Plantbakkiesistelsel het laer sorghum opbrengs as gevolg van afname in plantstand wat deur knaagdiere geteister is by

gewasvestigingsstadium. Dieselfde proef het getoon dat die sorghum en akkerboon by die 0.9 m x 0.6 m spasiëring van die bakkiesisteem sal groei sonder noemenswaardige afname in opbrengs vergeleke met die konvensionele sisteem.

Die grondwaterdinamika van die enkel konvensionele en dubbelploeg, skeurploeg en bakkiegrondbewerkingsisteme is gevind as redelik ooreenstemmend. Die stasieproef het ook soortgelyke grondwaterdinamika in konvensionele, skeurploeg en bakkiesisteme onder deklaetoestande by Matopos (kleigrond) en Lucydale (sandgrond), blootgelê. Die bakkiesisteem het meer grondwater gedurende die begin van die November-Desember groeiseisoen bevat. Oppervlakaflaolesings het aangedui dat bakkies waterverliese vanaf beide verboude en onverboude landerye verminder. Die afname in oppervlakaflao en hoër aanvanklike grondwaterinhoud het egter nie daartoe bygedra tot hoër opbrengstes onder die bakkiegrondbewerkingssisteem in vergelyking met ander grondbewerkingsisteme nie.

Die studie van grondwaterbydrae tot waterpasgelyke kontoere en infiltrasiepitte het aan die lig gebring dat hierdie tussen-landerye stukture geen effek gehad het op grondprofielwaterinhoud binne seisoene met ondernormale reënval nie. Gedurende seisoene met daaglikse reënvalgevalle van meer as 30 mm, het die waterpasgelyke kontoere en infiltrasiepitte meer reënwater versamel as slegs die waterpas kontoere. Laterale grondwaterbewegings het plaasgevind na reënvalgevalle van 60-70 mm, veral teen die skuinste van die kontoer, met noemenswaardige veranderinge in grondwater waargeneem op 'n afstand 3 m van die kontoer. Die waterpasgelyke kontoere en

infiltrasiepitte het grondwater verskaf aan die 0.25-0.45 m lae van die 0.6 m profiel gebruik by hierdie studie.

Die evaluasie van die *in situ* grondbewerkingsisteme deur kleinhoeweboere het getoon dat arbeidsvereistes en gewasopbrengstes as belangrike faktore deur kleinhoeweboere in semi-ariëde suidelike Zimbabwe oorweeg word, by tegnologiese keuses. Die groot meerderheid boere het die hoogste opbrengstes onder dubbelploegsisteem behaal, en daarom het hulle dit verkies as die mees geskikte grondbewerkingsisteem vir verbruik onder die gegewe toestande. Besikbaarheid van graan en peulsade is een van die grootse probleme ondervind by alle steekproef huishoudings in die Gwanda en Insiza distrikte gedurende die studieperiode. Die langtermyn assessering van die bakkiesisteem deur middel van simulatie modelering het getoon dat bakkies slegs marginale opbrengs voordele bo die konvensionele sisteem behaal het, ongeag die stikstofvlak gebruik. Die langtermyn simulatie het ook aangedui dat gewasmislukkings by beide konvensionele asook bakkiesisteme voorkom, hoofsaaklik as gevolg van oneweredige verspreiding van reënvalgevalle deur die groeiseisoen.

TABLE OF CONTENTS

Title	i
Declaration	ii
Acknowledgements	iii
Abstract	iv
Uittreksel	ix
Table of Contents	xiv
List of Tables	xvi
List of Figures	xxii
List of symbols and abbreviations	xxxi
CHAPTER 1: General Introduction	1
CHAPTER 2: Literature Review	6
CHAPTER 3: General Materials and Methods	29
CHAPTER 4: Characterisation of Rainfall Pattern for Improved Crop Production in Semi-Arid Cropping Systems of Southern Zimbabwe	46
CHAPTER 5: Soil Water and Fertility Management Practices on Smallholder Farms in Insiza and Gwanda Districts of Semi-Arid Southern Zimbabwe	81
CHAPTER 6: Farm Characteristics and Evaluation of Soil Water and Fertility Management Options for Smallholder Semi-Arid Cropping Systems	110
CHAPTER 7: Integrated Tillage and Nitrogen Management for Improved Soil and Water Productivity on Smallholder Farms in Semi-Arid Zimbabwe	137
CHAPTER 8: Effect of Dead Level Contours and Infiltration Pits on Soil Water Content and Crop Yields on Smallholder Farms in Gwanda District,	

Southern Zimbabwe	174
CHAPTER 9a: Soil Water and Maize Yield Responses to Minimum Tillage and Mulching on Clayey and Sandy Soils in Semi-Arid Southern Zimbabwe	202
CHAPTER 9b: Minimum Tillage and Mulching Effects on Soil Water Regimes, and Cowpea and Sorghum Yields on a Red Clay Soil in Semi-Arid Southern Zimbabwe	238
CHAPTER 9c: Cumulative Effects of Minimum Tillage, Mulching and Rotation on Selected Soil Properties and Maize Yield on a Clayey Soil in Semi-Arid Southern Zimbabwe	262
CHAPTER 10: Productivity of Planting Basin Tillage System and Nitrogen under Highly Variable Rainfall Regimes of Semi-Arid southern Zimbabwe: A Modelling Assessment	292
CHAPTER 11: Summary and Recommendations	316
REFERENCE	330
APPENDIX 1	355
APPENDIX 2	357

List of Tables

Table 2.1.	Effect of double spring ploughing on sorghum grain yield for seven soil types in Botswana in 1988/89	15
Table 3.1.	Geographical description of meteorological stations and rainfall database of the five stations used in the analyses	34
Table 3.2.	Experimental fields used and crops grown in each field from 2004/05 to 2007/08 seasons at Matopos Research Station	42
Table 4.1.	Drought classification indices adapted from Hayes <i>et al.</i> (1999)	49
Table 4.2.	Homogeneity test for annual total rainfall for the five meteorological stations in southern Zimbabwe	51
Table 4.3.	Characteristics of the total annual rainfall (based on July-June calendar) recorded at five meteorological stations in semi-arid southern Zimbabwe	52
Table 4.4.	Median dates for the start and end of the growing season based on daily rainfall data obtained from five meteorological stations in southern Zimbabwe	63
Table 4.5.	Rainfall characteristics for first half of the growing season at five stations in semi-arid southern Zimbabwe	76
Table 4.6	Rainfall characteristics for second half of the growing season at five stations in semi-arid southern Zimbabwe	77
Table 5.1.	Effect of combining manure or compound D (8:14:7 – N:P ₂ O ₅ :K ₂ O) with modified tied ridges on crop yield in Gwanda district (after Rusike and Heinrich, 2002)	86
Table 5.2.	Rainfall patterns and maize grain yield (kg ha ⁻¹) responses to farmer practice and planting basins for eight districts in southern Zimbabwe in 2004/2005, (after Twomlow <i>et al.</i> 2006a)	88
Table 5.3.	Major soil types, crop areas and possible yields in a good growing season in ward 1 of Insiza district	91
Table 5.4.	Characteristics of different winter and growing seasons and crops grown as reported by farmers in ward 1 of Insiza district	94

Table 5.5.	Soil fertility amendments applied during bad and good seasons by farmers in ward 1, Insiza district	96
Table 5.6.	Risk factors and their severity on household food security as identified by farmers in ward 1 of Insiza district	97
Table 5.7.	Major soil types, crop areas and possible grain production in a good growing season in Gwanda district	97
Table 5.8.	Crop production in good and bad farming seasons in Gwanda district ...	99
Table 5.9.	Characteristics of different winter and growing seasons and crops grown as observed by farmers in Gwanda district	105
Table 5.10.	Characteristics of different winter and growing seasons and crops grown as observed by farmers in Gwanda district	106
Table 5.11.	Risk factors and their severity on household food security as identified by farmers in Gwanda district	107
Table 6.1.	Farmer resource status as an average of Gwanda and Insiza districts of southern Zimbabwe	114
Table 6.2.	Cropping calendar for the farmer practice fields in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons	122
Table 6.3.	Cropping calendar for the single conventional ploughing in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons	122
Table 6.4.	Cropping calendar for the double conventional ploughing in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons	122
Table 6.5.	Cropping calendar for the ripper system in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons	123
Table 6.6.	Cropping calendar for the basin system in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons	123
Table 6.7.	Farmer assessment of labour demands for land preparation on a 0.25 ha plot of different tillage systems tested on their farms averaged for three growing seasons	126

Table 6.8.	Farmer assessment of weeding methods, frequency and labour demands during seasons with different rainfall pattern in Gwanda and Insiza districts	127
Table 6.9.	Pest species in different tillage system affected as observed by farmers in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons	131
Table 6.10.	Farmer ranking of organisations working in Gwanda and Insiza, and support rendered and expected by farmers in Gwanda and Insiza districts. (1 = lot of support; 5 = little support)	134
Table 7.1.	Selected initial soil chemical and physical properties (0 – 0.6 m) at farms used from 2005/06 to 2007/08, Insiza and Gwanda districts	146
Table 7.2.	Average maize plant stands under four tillage systems (CP, DP, ripper and basin) measured two weeks after crop emergence during the three seasons of experimentation in Insiza and Gwanda districts	159
Table 7.3.	Maize responses to four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0 and 10 kgNha ⁻¹) averaged across five farms in 2005/06 season, Insiza and Gwanda districts	160
Table 7.4.	Maize responses to four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer averaged across three farms in 2006/07 season, Insiza and Gwanda districts	161
Table 7.5.	Maize responses to four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0, 10 and 20 kgNha ⁻¹) averaged across seven farms in 2007/08 season, Insiza and Gwanda districts	162
Table 7.6.	Effects of season and tillage system on maize crop performance during three seasons of experimentation in Insiza and Gwanda districts	163
Table 7.7.	Effects of season and nitrogen fertilizer on maize crop performance during three seasons of experimentation in Insiza and Gwanda districts	163
Table 7.8.	Agronomic nitrogen use efficiency of maize in four tillage systems (CP, DP, ripper and basin) averaged across farms for each season during 2005/06, 2006/07 and 2007/08 growing seasons Insiza and Gwanda districts	166

Table 8.1.	Soil textural variation with soil depth at the four farms used for quantifying soil water supply from dead level contours and infiltration pits in Gwanda district	181
Table 8.2.	Components of water balance averaged across two farms (Moyo and Ncube) at each distance along unploughed and ploughed transects the during 2007/08 eason.....	198
Table 8.3.	Components of the soil water balance averaged across two farms (Dube and Siziba) at each distance along unploughed and ploughed transects across dead level contours and infiltration pits during 2007/08 season	198
Table 8.4.	Pearl millet and maize yields and water use efficiency between different positions from dead level contour averaged across two farms (Moyo and Ncube) along the ploughed transect at the end of the 2007/08 growing season	199
Table 8.5.	Pearl millet and maize yields and water use efficiency between different positions from dead level contour averaged across two farms (Dube and Siziba) with dead level contours and infiltration pits along the ploughed transect at the end of 2007/08 season	200
Table 9a.1.	Experimental fields used and crops grown in each field from 2004/05 to 2007/08 seasons at Matopos Research Station	205
Table 9a.2.	Physical and chemical characteristics of Matopos and Lucydale soils, after Moyo (2001)	208
Table 9a.3.	Characteristics of the 2004/05 and 2005/06 growing seasons at Lucydale experimental site	210
Table 9a.4.	Effects of tillage and mulch treatments on maize crop performance at Lucydale experimental site in 2004/05 growing season	214
Table 9a.5.	Effects of tillage and residual mulch treatments on maize crop performance at Lucydale experimental site in 2005/06 growing season	215
Table 9a.6.	Characteristics of the 2004/05, 2005/06, 2006/07 and 2007/08 growing seasons at Matopos experimental site	217

Table 9a.7.	Effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2004/05 growing season	227
Table 9a.8.	Effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2005/06 growing season	227
Table 9a.9.	Effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2006/07 growing season	229
Table 9a.10.	Effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2007/08 growing season	231
Table 9a.11.	Effects of tillage and mulching on maize performance averaged across four growing seasons at Matopos experimental site	233
Table 9a.12.	Effect of the growing season on maize crop performance at Matopos experimental site	234
Table 9a.13.	Effects of tillage and mulching on maize performance averaged across four growing seasons at Matopos experimental site	235
Table 9b.1.	Effect of tillage method and mulch cover on cowpea plant stand two weeks after planting (plants m ⁻²) on a red clay soil at Matopos Research Station	256
Table 9b.2.	Effect of tillage system and mulch treatment on sorghum stand two weeks after planting (plants m ⁻²) on a red clay soil at Matopos Research Station	257
Table 9b.3.	Cowpea grain yield responses (kg ha ⁻¹) averaged across three tillage systems and seven mulch levels at Matopos Research Station during 2005/06 and 2006/07 growing seasons	258
Table 9b.4.	Sorghum yield responses (kg ha ⁻¹) averaged across three tillage systems and seven mulch treatments at Matopos Research Station during 2006/07 growing season	260
Table 9c.1.	Experimental fields used and crops grown in each field from 2004/05 to 2007/08 seasons at Matopos Research Station	264
Table 9c.2.	van Genuchten parameters for 12 textural classes and A values for 2.2 cm disk radius and suction values from 0.5 to 6.0 cm (Adapted from Carsel and Parrish, 1988)	268

Table 9c. 3.	Effect of tillage and period of exposure to CA practices averaged across three mulch levels (0, 4 and 10 t ha ⁻¹) on soil organic carbon content (%) of a clay soil at Matopos Research Station	270
Table 9c.4.	Effect of tillage, mulching and year interaction on soil bulk density of a red clay soil at Matopos Research Station	272
Table 9c.5.	Effect of minimum tillage, mulching and period of exposure to CA practices on soil hydraulic conductivity (K) (10 ⁻³ mms ⁻¹) and capillary sorptivity (S) (mm/√s) of a clay soil at Matopos Research Station	285
Table 9c.6.	Volumetric water content (%) measured by capacitance probe in 0 – 0.10 m soil layer before infiltration runs at Matopos Research Station	287
Table 9c.7.	Volumetric soil water content (%) in 0 – 0.10 m layer measured after infiltration runs in the four fields at Matopos Research Station	288
Table 9c.8.	Maize crop performance measured at the end of the 2007/08 season as influenced by different periods of exposure to CA practices on a clay soil at Matopos Research Station	289
Table 9c.9.	Maize yield (kg ha ⁻¹), harvest index and plant stand (m ⁻²) responses to three tillage methods at Matopos Research Station in 2007/08 season	290
Table 10.1.	Soil chemical and physical properties of the clay soil used for Matopos Research Station experimental site (from ICRISAT unpublished data)	296
Table 10.2.	Soil chemical and physical properties of the sand soil used for Lucydale experimental site (from Masikati, 2006)	296
Table 10.3.	Dates for field activities carried out at Matopos Research Station during the four seasons of experimentation (Chapter 9a)	297
Table 10.4.	Dates for field activities carried out at Lucydale experimental site during the two seasons of experimentation (Chapter 9a)	298
Table 11.1.	Typical cropping calendar for smallholder cropping systems of semi-arid southern Zimbabwe	318

List of Figures

Figure 2.1.	Agro-ecological regions of Zimbabwe (<i>Source: ICRISAT GIS office, 2008</i>)	13
Figure 3.1	Agro ecological regions of Zimbabwe and location of experimental sites in Insiza and Gwanda districts, Matebeleland South province	34
Figure 3.2.	Schematic diagram of the set up of equipment for collection of runoff water from the plots under single and double conventional ploughing, ripper and basin systems	38
Figure 3.3.	Schematic diagram of the set up of access tubes across dead level contours in Gwanda district	40
Figure 4.1.	Total annual rainfall (July to next June) for Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations of semi-arid southern Zimbabwe	53
Figure 4.2.	Total annual rainfall for Filabusi (d) and Beitbridge (e) meteorological stations of semi-arid southern Zimbabwe	54
Figure 4.3.	Standardized precipitation indices derived from total annual rainfall data for Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations	57
Figure 4.4.	Standardized precipitation indices derived from total annual rainfall data for Filabusi (d) and Beitbridge (e) meteorological stations	58
Figure 4.5.	Number of wet days per season based on daily rainfall data obtained from Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations ...	60
Figure 4.6.	Number of wet days per season based on daily rainfall data obtained from Filabusi (d) and Beitbridge (e) meteorological stations	61
Figure 4.7.	Start and end of growing seasons derived from daily rainfall data for Bulawayo (a), Matopos (b) and Mbalabala (c) Meteorological stations	64
Figure 4.8.	Start and end of growing seasons derived from daily rainfall data for Filabusi (d) and Beitbridge (e) meteorological stations	65
Figure 4.9.	Length of the growing season based on daily rainfall data obtained from Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations....	68

Figure 4.10.	Length of the growing season based on daily rainfall data obtained from Filabusi (d) and Beitbridge (e) meteorological stations	69
Figure 4.11.	Relationship between length and start of growing season at Bulawayo (a) meteorological station in southern Zimbabwe	70
Figure 4.12.	Relationship between length and start of growing season at Matopos (b), Mbalabala (c) and Filabusi (d) meteorological stations in southern Zimbabwe	71
Figure 4.13.	Relationship between length and start of growing season at Filabusi (d) and Beitbridge (e) meteorological stations in southern Zimbabwe	72
Figure 4.14.	Probability of getting 14 and 21 day spells within 30 days from a wet day based on the fitted first order Markov chain probability values for Bulawayo (a) and Matopos (b) meteorological stations in southern Zimbabwe	73
Figure 4.15.	Probability of getting 14 and 21 day spells within 30 days from a wet day based on the fitted first order Markov chain probability values Mbalabala (c), Filabusi (d) and Beitbridge (e) stations in southern Zimbabwe	74
Figure 4.16.	Cumulative distribution functions for the first and second halves of the growing season based on three monthly rainfall totals from Bulawayo (a) meteorological station	77
Figure 4.17.	Cumulative distribution functions for the first and second halves of the growing season based on three monthly rainfall totals from Mbalabala, Filabusi (d) and Beitbridge (e) meteorological stations	78
Figure 6.1.	Resource flow map for Mr. John Ncube of Gwanda district. The map represents flow of resources at a farm that interacted with researchers for three cropping seasons	117
Figure 6.2.	Resource flow map for Mrs. Malotha of Humbane village, Gwanda district. The map represents flow of resources at a farm that had no interaction with researchers from 2005/06 to 2007/08 seasons	119
Figure 6.3.	Average sources of sorghum seed planted by 14 households in 2005/06, 2006/07 and 2007/08 seasons in ward 1 of Insiza and ward 17 of Gwanda district	120

Figure 6.4.	Average sources of maize seed planted by 14 households in 2005/06, 2006/07 and 2007/08 seasons in ward 1 of Insiza and ward 17 of Gwanda district	121
Figure 6.5.	Farmer ranking of basin, double ploughing (DP) and ripper tillage systems tested on their fields for three growing seasons in Gwanda and Insiza districts. Ranking was based on maize grain yields achieved over three growing seasons	130
Figure 6.6.	Tillage systems chosen for adoption by female and male farmers during focus group discussions in Gwanda and Insiza districts	132
Figure 7.1.	Cumulative rainfall distribution at Mpofu and Moyo farms of ward 1 in Insiza district during 2005/06 growing season	147
Figure 7.2.	Profile soil water changes (0 – 0.50 m) averaged across two farms (Moyo and Mpofu) in ward 1 of Insiza district during 2005/06 growing season.	148
Figure 7.3.	Cumulative rainfall distribution at Sibanda, Siziba and J. Ncube farms of ward 17 in Gwanda district during 2005/06 growing season	149
Figure 7.4.	Profile soil water changes (0 – 0.60 m) averaged across three farms in ward 17 of Gwanda district during 2005/06 growing season	150
Figure 7.5.	Cumulative rainfall distribution at Mpofu, Nyathi, Mguni and Mlalazi farms of ward 1 in Insiza district during 2006/07 growing season	151
Figure 7.6.	Profile soil water changes (0 – 0.60 m) averaged across two farms (Mpofu and Nyathi) in ward 1 of Insiza district during 2006/07 growing season.	152
Figure 7.7.	Cumulative rainfall distribution at Sibanda, Siziba and J. Ncube farms of ward 17 in Gwanda district during 2006/07 growing season	153
Figure 7.8.	Profile soil water changes (0 – 0.60 m) averaged across three farms (Sibanda, Siziba and J. Ncube) in ward 17 of Gwanda district during 2006/07 growing season.	153
Figure 7.9.	Cumulative rainfall distribution at Mpofu, N. Ncube, Nkomo, Mguni and Mlalazi farms of ward 1 in Insiza district during 2007/08 growing season	154

Figure 7.10.	Profile soil water changes (0 – 0.60 m) averaged across three farms (Mpofu, N. Ncube and Nkomo) in ward 1 of Insiza district during 2007/08 growing season	155
Figure 7.11.	Cumulative rainfall distribution at Sibanda, Siziba, J. Ncube and Tlou farms of ward 17 in Gwanda district during 2007/08 growing season ...	156
Figure 7.12.	Profile soil water changes (0 – 0.60 m) averaged across three farms (J. Ncube, Sibanda and Siziba) in ward 17 of Gwanda district during 2007/08 growing season	157
Figure 7.13.	Seasonal runoff losses from plots under four tillage systems in 2006/07 growing season, Insiza (Mpofu and Nyathi) and Gwanda (J. Ncube and Sibanda) districts	158
Figure 7.14.	Seasonal runoff losses from plots under four tillage systems in 2007/08 growing season, Insiza (Mpofu and N. Ncube) and Gwanda (J. Ncube and Sibanda) districts	159
Figure 7.15.	Water use efficiency as affected by four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0 and 10 kgNha ⁻¹) across five farms (Moyo, Mpofu, J. Ncube, Sibanda and Siziba) in 2005/06 season, Insiza and Gwanda districts	164
Figure 7.16.	Water use efficiency as affected by four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0, 10 and 20 kgNha ⁻¹) across six farms in 2007/08 season, Insiza and Gwanda districts	165
Figure 8.1.	Drained upper limit (DUL) and lower limit (LL) derived from 2007/08 soil water data for Moyo, Ncube and Dube farms in Gwanda district ...	180
Figure 8.2.	Drained upper limit (DUL) and lower limit (LL) derived from 2007/08 soil water data for Siziba farm in Gwanda district	181
Figure 8.3.	Cumulative rainfall distribution at Moyo, Ncube, Dube and Siziba farms of ward 17 in Gwanda district during 2006/07 growing season	183
Figure 8.4.	Cumulative rainfall distribution at Moyo, Ncube, Dube and Siziba farms of ward 17 in Gwanda district during 2006/07 growing season	184

Figure 8.5.	Profile soil water changes along ploughed transects averaged across two farms with dead level contours only (Moyo and Ncube) during the 2006/07 growing season	185
Figure 8.6.	Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on the driest day along unploughed (a) and ploughed (b) transects during 2006/07 season	186
Figure 8.7.	Profile soil water changes averaged across two farms (Moyo and Ncube) along unploughed (a) and ploughed (b) transects across farms with only dead level contours during 2007/08 growing season	187
Figure 8.8.	Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on the driest day along unploughed transect during 2007/08 season	188
Figure 8.9.	Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on the driest day along ploughed transect during 2007/08 season	189
Figure 8.10.	Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on wettest day along unploughed (a) and ploughed (b) transects during 2007/08 season	190
Figure 8.11.	Profile soil water changes at different distances from the dead level contour with infiltration pit averaged across two farms (Dube and Siziba) during 2006/07 growing season	192
Figure 8.12.	Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on driest and wettest days during 2006/07 season	193
Figure 8.13.	Profile soil water changes along unploughed (a) and ploughed (b) transects at farms with dead level contours and infiltration pits averaged across two farms (Dube and Siziba) during 2007/08 growing season ...	194
Figure 8.14.	Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube	

	and Siziba) on driest day along unploughed transect during 2007/08 season	195
Figure 8.15.	Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on driest day along ploughed transect during 2007/08 season	196
Figure 8.16.	Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on wettest day along unploughed (a) and ploughed (b) transects during 2007/08 season	197
Figure 9a.1.	Daily rainfall distribution at Lucydale experimental site during 2004/05 and 2005/06 growing seasons	210
Figure 9a.2.	Average seasonal soil water content in the 0–0.30 m profile at Lucydale during 2004/05 cropping season	211
Figure 9a.3.	Soil water content in the 0–0.60 m profile at Lucydale during 2005/06 cropping season	212
Figure 9a.4.	Cumulative rainfall distribution at Matopos experimental site during 004/05, 2005/06, 2006/07 and 2007/08 growing seasons	217
Figure 9a.5.	Average seasonal soil water content in the 0 – 0.30 m profile under three tillage systems and mulching treatments at Matopos during 2004/05 season	221
Figure 9a.6.	Soil water content in the 0 – 0.30 m profile at Matopos during 2005/06 cropping season	221
Figure 9a.7.	Profile soil water changes in the conventional ploughing, ripper and basin system and four mulch treatments (0, 2, 4 and 10 tha^{-1}) at Matopos experimental site during 2006/07 growing season	223
Figure 9a.8.	Soil water changes in four different layers of the soil profile under the conventional ploughing tillage system during 2006/07 growing season at Matopos site	224

Figure 9a.9.	Profile soil water changes in the conventional, ripper and basin tillage systems and four mulch treatments (0, 2, 4 and 10 t ha ⁻¹) at Matopos experimental site during 2007/08 growing season.....	225
Figure 9a.10.	Soil water changes in four different layers of the soil profile during 2007/08 growing season at Matopos experimental site	226
Figure 9a.11.	Maize grain yield responses to mulching on a red clay soil under conventional, ripper and basin tillage system during the 2006/07 growing season	232
Figure 9b.1.	Daily rainfall distribution at Matopos site during the 2005/06 growing season	243
Figure 9b.2.	Soil water changes in 0 – 0.30 m profile in the cowpea field under conventional ploughing tillage system and four mulch treatments (0, 2, 4 and 10 t ha ⁻¹) on a clay soil during 2005/06 growing season	245
Figure 9b.3.	Soil water changes in 0 – 0.30 m profile in the cowpea field under two tillage systems (ripper and basin) and four mulch treatments (0, 2, 4 and 10 t ha ⁻¹) on a clay soil during 2005/06 growing season	246
Figure 9b.4.	Daily rainfall distribution at Matopos site during the 2006/07 growing season	248
Figure 9b.5.	Profile soil water changes in 0 – 0.55 m profile in the cowpea field under two tillage systems (ripper and basin) and four mulch treatments (0, 2, 4 and 10 t ha ⁻¹) on a clay soil during 2006/07 growing season	249
Figure 9b.6.	Average changes in equivalent soil water depth in different layers of a clay soil under conventional ploughing tillage system in the cowpea field at Matopos Research Station during 2006/07 growing season	250
Figure 9b.7.	Average changes in equivalent soil water depth in different layers of a clay soil under ripper and basin tillage systems in the cowpea field at Matopos Research Station during 2006/07 growing season	252
Figure 9b.8.	Soil water changes (0 – 0.65 m profile) in response to conventional, ripper and basin tillage systems and four mulching treatments (0, 2, 4 and 10 t ha ⁻¹)	

	l) in the sorghum field during 2006/07 growing season at Matopos Research Station	254
Figure 9c.1.	Effect of tillage and soil depth on organic carbon content (%) of a red clay soil at Matopos Research Station	271
Figure 9c.2.	Soil bulk density distribution with respect to soil depth in different tillage treatments in field 1 (first year of CA treatments) at Matopos Research Station	276
Figure 9c.3.	Soil bulk density distribution with respect to soil depth in different tillage treatments and fields at Matopos Research Station	277
Figure 9c.4.	Effect of conventional ploughing and ripper systems, 0 tha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil	279
Figure 9c.5.	Effect of basin system, 0 tha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil	280
Figure 9c.6.	Effect of tillage, 4 tha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil	281
Figure 9c.7.	Effect of tillage, 10 tha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil	283
Figure 10.1.	Observed and predicted grain yield from different mulch levels over four growing seasons at Matopos Research Station	301
Figure 10.2.	Observed and predicted total biomass yields from different mulch levels over four growing seasons at Matopos Research Station	302
Figure 10.3.	Observed and predicted grain and total biomass yields for different mulch levels on a sand soil over two growing seasons at Lucydale experimental site	304
Figure 10.4.	Observed and predicted soil water content in a clay soil (0 – 0.25 m layer) under plough, ripper and basin tillage systems at Matopos Research Station during 2006/07 growing season	306
Figure 10.5.	Observed and predicted soil water in a clay soil (0 – 0.25 m layer) under plough, ripper and basin tillage systems at Matopos Research Station during 2007/08 growing season	307

Figure 10.6.	Observed and predicted soil water in a clay soil (0 – 0.25 m layer) under plough (a), ripper (b) and basin (c) tillage systems at Matopos Research Station during 2007/08 growing season	308
Figure 10.7.	Comparison of grain yield achieved in the conventional and basin tillage systems at four N application rates (0, 10, 20 and 52 kgNha ⁻¹) on a granitic sandy soil under semi-arid conditions	310
Figure 10.8.	Cumulative distribution function for maize grain yield response to four N application rates (0, 10, 20 and 52 kgNha ⁻¹) on a granitic sandy soil in the conventional tillage system under semi-arid conditions	311
Figure 10.9.	Cumulative distribution function for maize grain yield response to four N application rates (0, 10, 20 and 52 kgNha ⁻¹) on a granitic sandy soil in the basin tillage system under semi-arid conditions	312
Figure 10.10.	Surface runoff water losses from the conventional ploughing and basin tillage systems on a granitic sandy soil under semi-arid conditions	313
Figure 10.11.	Deep drainage soil water losses from conventional ploughing and basin tillage systems during the crop growing period under semi-arid conditions	314

List of Symbols and Abbreviations

AGRITEX	Zimbabwe Department of Agricultural technical and extension
ANOVA	Analysis of variance
ANUE	Agronomic nitrogen use efficiency
APSIM	Agricultural Production Simulator
AREX	Agricultural Extension Services
C	Capillary rise
CA	Conservation agriculture
CADEC	Catholic Development Commission
CIMMYT	International Maize and Wheat Improvement Centre
CP	Conventional ploughing
CV	Coefficient of variation
D	Deep drainage
DFID	United Kingdom Department for International Development
DLC	Dead level contour
DP	Double ploughing
DRSS	Zimbabwe Department of Research and Specialist Services
DUL	Drained upper limit of soil water content
ECAF	European Conservation Agriculture Federation
ENSO	El Niño-Southern Oscillation
ET	Evapotranspiration rate
FAO	United Nations Food and Agricultural Organization
GCM	Global Circulation Model or Global Climate Model
GMB	Zimbabwe Grain marketing board
GTZ	Germany Agency for Technical Cooperation
IAE	Zimbabwe Institute of agricultural engineering
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ITCZ	Inter-tropical convergence zone
LL	Lower limit of soil water content
Lsd	Least significant difference
ME	Modeling efficiency

NGO	Non-Governmental Organization
NR	Zimbabwe Agroecological region
O_i	Observed values
ORAP	Organization of Rural Associations for Progress
P	Precipitation (mm)
PAWC	Plant available water capacity
P_i	Model predicted values
PRA	Participatory Rural Appraisal
REML	Restricted maximum likelihood model
RMSD	Root mean square deviation
Runoff	Surface runoff out of the field (mm)
Ron	Surface runoff into the field (mm)
SAFIRE	Southern Alliance for Indigenous Resources
se	Standard error of means
SEDAP	South eastern dry areas project
sed	standard error of difference
SPI	Standardized precipitation index
SST	Seas Surface Temperature
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WUE	Water use efficiency
ΔSW	Change in soil water (mm)
ΔY	Change in grain yield (kg ha^{-1})
ZFC	Zimbabwe Fertilizer Company

CHAPTER 1

1.1 Background

Every year an estimated six million hectares of productive land are being lost through desertification, land degradation and declining agricultural productivity (UNDP, 2002). The population of Africa is expected to reach 1.2 billion by the year 2020 (Love *et al.*, 2006). This means more 'mouths' have to be fed from a diminishing resource base (Diagana, 2003), and leads to overgrazing and cultivation of marginal lands (Ngwenya, 2006; Twomlow *et al.*, 2006a). Agricultural production of major cereals and legumes has remained stagnant or even declined in most African countries (Henao and Baanante, 2006). In Zimbabwe, more than 75% of smallholder farming families, who depend on rainfed agriculture, live in the semi-arid areas of agroecological regions (NR) IV and V (Chuma and Haggmann, 1998) where rainfall is erratic and soils are inherently infertile.

Smallholder agriculture in semi-arid sub-Saharan Africa is heavily dependant on the seasonal characteristics of the rainfall. Total annual rainfall in semi-arid southern Zimbabwe is less than 500 mm (against a national average of 657 mm) and exhibits extreme spatial and temporal variations (Unganai, 1996; Phillips *et al.*, 1998). According to the agro-ecological classification of Zimbabwe based on climate and soils, NRs IV and V are not suitable for intensive rainfed crop production (Vincent and Thomas, 1960) due to low and highly variable annual rainfall. Rainfall occurs as short duration, high intensity convective storms (Rockström and Falkenmark, 2002). Complete crop failure and reduced crop yields due to frequent intra-seasonal dry spells and drought make rainfed crop production risky. Soil water availability remains

one of the major challenges to crop production in NRs IV and V given the erratic rainfall pattern.

Despite the use of drought-tolerant maize, sorghum and pearl millet varieties, farmers in semi-arid southern Zimbabwe still achieve small yield gains. The potential yields for sorghum and millet range between 1.7 and 4.8 tha^{-1} but average yields in Zimbabwe are currently less than 0.6 tha^{-1} (Ahmed *et al.*, 1997). Most soils in the smallholder farming areas are sands derived from granitic parent material (Grant, 1981) with poor water holding capacity, low inherent soil fertility and organic matter (Anderson *et al.*, 1993) making them marginal for crop production (Twomlow, 1994).

Lack of inorganic and/or organic fertilizer use is undermining household food security in the semi-arid areas. In semi-arid southern Zimbabwe fertilizer and livestock manure usage is also low and the free handouts of fertilizer have failed to stimulate farmers to use more soil fertility amendments (Ahmed *et al.*, 1997). Farmer perception of fertilizer usage is that it is too risky given the low and erratic nature of rainfall in the region. Many farmers in the semi-arid areas have had few positive experiences with organic and inorganic fertilizers. However, studies conducted by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) across 17 districts in southern Zimbabwe have shown that cereal yield gains of 30–50% are achievable using small doses (10 kgNha^{-1}) of nitrogen in a normal season (Twomlow *et al.*, 2008b). Supplementing livestock manure with small doses of nitrogen fertilizer gives maize yield gains even in seasons with severe plant water stress (Ncube *et al.*, 2007).

Low crop productivity in smallholder farming systems is further exacerbated by poor management. Appropriate timing of field operations such as planting and weeding is a potential key to successful cropping in semi-arid areas. Late planting in most instances is due to lack of draught power resulting in farmers failing to utilize the effective planting rains. Nyagumbo (2007) reports that delaying planting by more than 3 weeks can reduce maize yield by 32 % in sub humid northern Zimbabwe. Excessive weed growth is one of the major factors limiting crop production in smallholder farming systems (Dhliwayo *et al.*, 1995). Field studies have shown that weed transpiration has a significant impact on soil water regimes in semi-arid environments (Van der Meer, 2000). Besides reducing unproductive water flows through weed transpiration, effective weed control also reduces competition for nutrients and radiation between crops and weeds.

A range of interventions that collect and conserve rainwater and prolong the time of soil water availability to crops are currently being developed and promoted in the semi-arid cropping systems of southern Zimbabwe. Such *in situ* techniques include planting basin and ripper tillage systems which are part of the recently introduced Conservation Agriculture (CA) program (Twomlow and Hove, 2006). By using a planting basin system, smallholder farmers with limited access to animal draught power can plant on time in terms of a few days after an effective rainfall event (Twomlow *et al.*, 2008a). Dead level contours and infiltration pits are between field structures designed to collect runoff water from the field and supply soil water to crops through lateral movement from the contours. However, the contribution of both *in situ* tillage systems and between field rainwater harvesting structures to soil water

dynamics and crop yields under semi arid cropping systems is not well understood in terms of soil water storage and use.

1.2 Hypotheses

In order to understand the effect of rainwater management techniques and nitrogen on soil water dynamics and crop yields in semi-arid cropping systems, the following hypotheses were tested:

- (1) Smallholder farmers in Gwanda and Insiza districts are currently using available soil water and fertility management practices.
- (2) Rainfall patterns and growing seasons in semi-arid southern Zimbabwe have been changing over the past 50 to 74 years.
- (3) The use of minimum tillage techniques such as planting basins and ripping, and nitrogen fertilizer with or without mulching improves soil water supply and crop yields in semi-arid cropping systems.
- (4) Dead level contours and infiltration pits supply soil water laterally to crops resulting in increased yields.
- (5) The use of planting basin tillage system and nitrogen fertilizer improves maize yields and reduces risk in semi-arid smallholder cropping systems.

1.3 Objectives

The current study was designed to quantify soil water benefits derived from *in situ* and inter-field water management techniques in semi-arid Gwanda and Insiza districts of southern Zimbabwe. The study also explored synergies between soil water and nitrogen management for improved water and crop productivity in semi-arid cropping systems. Simulation modelling was applied to assess the long-term effect of planting

basin tillage system and nitrogen on maize productivity and the soil water balance in smallholder cropping systems. The specific objectives were:

- (1) To identify current soil water and fertility management practices and farmers' perceptions of risk in Gwanda and Insiza districts;
- (2) To characterise rainfall and growing season patterns of the semi-arid southern Zimbabwe;
- (3) To quantify the effects of *in situ* minimum tillage techniques and N fertilizer on soil water dynamics and maize yields;
- (4) To quantify the effects of *in situ* minimum tillage techniques and mulching on soil water dynamics, and cowpea, maize and sorghum yields;
- (5) To evaluate the effect of dead level contours and infiltration pits on in-field soil water dynamics in Gwanda district;
- (6) To conduct a farmer evaluation of *in situ* soil water and fertility management systems being promoted in Gwanda and Insiza districts; and
- (7) To assess the long-term effect of planting basin tillage system and nitrogen on maize productivity and soil water balance in smallholder cropping systems using APSIM systems model.

CHAPTER 2

Literature Review

2.1 Conservation agriculture

The introduction of the conventional plough in the 19th century enabled farmers to till more land and control problematic weeds (Stocking, 1989). Conventional ploughing became the '*civilized*' way of land preparation resulting in expansion of cropped land area in the smallholder farming sector (Alvord, 1936). Continuous cultivation has led to the loss of physical, chemical and biological soil properties responsible for maintaining soil health (Xiano-Bin *et al.*, 2006; Nhamo, 2007). Cereal yields from the smallholder farming sector of sub-Saharan Africa continue to decline at a time when Africa's population is expected to double the 1995 figures by the year 2020 (Love *et al.*, 2006).

Conservation agriculture (CA) has the potential to address some of the challenges being faced in the smallholder rainfed agriculture (Giller *et al.*, 2008). Conservation agriculture is a farming system that encompasses the use of minimum tillage, animal and tractor drawn implements, or hand powered methods, together with integrated pest and disease management (Twomlow *et al.*, 2008a). The CA system also emphasizes the integrated management of soil and water resources. Conservation agriculture systems hinge on three cornerstones: (1) minimum disturbance of the soil, (2) keeping the soil covered as much as possible with a minimum cover of 30 %, and (3) mixing and rotating crops (ECAAF, 1999; Baudeon *et al.*, 2007).

In southern Africa CA has been practiced in the large-scale commercial farming sector (Oldrieve, 1993; Haggblade and Tembo, 2003; Nyagumbo, 2007). The

commercial farmers have access to appropriate equipment and crop residues for mulching, and realised profits due to reduced land preparation costs and less wear on implements (Nyagumbo, 2007). After attaining independence Zimbabwe evaluated and promoted CA techniques such as no-till tied ridges, clean and mulch ripping, no-till strip cropping and tied furrows (Vogel, 1992; Twomlow and Dhlwayo, 1999; Twomlow and Bruneau, 2000; Nyagumbo, 2002). The research results indicated crop yield, soil and water conservation benefits derived from using the developed CA techniques (Smith, 1988; Vogel, 1992; Twomlow and Bruneau, 2000; Nyagumbo, 2002).

Despite the efforts made in developing and promoting CA techniques and the benefits shown by research results, adoption in the smallholder farming sector has remained low for various reasons that include the top-down approach used during the development of the technologies as well as the lack of appropriate equipment for CA practices (Nyagumbo, 2007). For example specialized equipment is required for planting and weeding in unploughed and mulched fields (Friedrich and Kienze, 2007). One of the major challenges to adoption of CA technologies developed for the smallholder sector is the availability of adequate labour on the farm as well as farming inputs. In semi-arid areas where livestock plays a more critical role than crops in the livelihood of households, competition for crop residues between livestock and crop sub-systems poses a threat to adoption of mulching (Palm *et al.*, 1997). If higher levels of production are reached then livestock would also benefit from the improvements in crop production. The use of cereal residues and livestock manure with high C:N ratio can promote temporary immobilization of soil nitrogen (Giller *et*

al., 1997; Palm *et al.*, 1997; Abiven and Recous, 2007) resulting in depressed crop yields.

2.2 Semi-arid smallholder cropping system

Crop production in semi-arid smallholder farming sector is strongly integrated with livestock activities. The crop enterprise depends on livestock mainly for draught power and manure. Draught power is required for land preparation and transport, and donkeys are the major source of draught power in semi-arid southern Zimbabwe. Cattle manure is available in relatively larger quantities than goat or sheep manure in most parts of Zimbabwe (Mapfumo and Giller, 2001). However, in semi-arid districts goat manure is predominant in some communities such as Kezi in Matebeleland South (Ahmed *et al.*, 1997). Crops are grown for dual purposes namely household food and as cash crops (Ncube, 2007). The cash is spent on paying school fees, buying agricultural inputs (seed, fertilizer, farm equipment etc.) and food among other household requirements.

The major crops grown include cereals such as maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R.Br.) and legumes namely bambara nut (*Vigna subterranean* (L.) Verdc), groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata* (L.) Walp). Cereals are grown on more than 70 % of cultivated area while legumes take up the remaining portion (Twomlow *et al.*, 2006b). Intercropping is a common practice with full crop rotation rarely practised by smallholder farmers. Lack of adequate seed hampers the production of legumes at a large scale in semi-arid areas (Ncube, 2007). Minor crops usually grown together with cereals include sunflower (*Helianthus annuus* L.),

watermelons (*Citrullus lanatus* (Thunb), sweet potatoes (*Ipomoea batatas*), sweet sorghum (*Sorghum vulgare* Pers.) and pumpkins (*Cucurbita maxima* L.).

Land preparation often starts in October-November but this activity can be delayed because draught animals are in poor condition at that time of the year (Shumba *et al.*, 1992). The recommended ploughing depth of 0.23 – 0.25 m is rarely achieved on smallholder farms because of poor plough settings and other plough conditions (Smith, 1988). Tsimba *et al.* (1999) observed that smallholder farmers managed a 0.11 – 0.15 m ploughing depth in a study conducted in Mutoko and Chinyika communal areas. Small grains are planted first with maize being planted as late as February. Legumes are normally planted during December and January. Planting date is season dependant as the onset of the first effective rains signalling the start of cropping period varies from year to year. Most weeding takes place within the first two months after crop emergence (Van der Meer, 2000). Hand weeding or ox-drawn cultivation followed by hand hoeing are common practices for weed control. Frequency of weeding operations depends on the rainfall pattern for each season with a single weeding being common in a dry cropping season and three or more weeding in a wet year. Problem weeds include striga (*Striga asiatica* (L.) Kuntze) and couch grass (*Cynodon guyana* L.).

In the low input crop production systems of the smallholder sector, maize and sorghum yields are often below 1.0 and 0.2 tha^{-1} respectively (Twomlow *et al.*, 2006b). In the south western Tsholotsho district of semi-arid Zimbabwe yields of 0.4 tha^{-1} for cowpea, 0.5 tha^{-1} for pearl millet, 0.7 tha^{-1} for sorghum and 0.8 tha^{-1} maize have been reported by the Department of Research and Extension (AREX) (Ncube,

2007). The Zimbabwe national yield averages for groundnuts and cowpea are 0.3 and cereals is 0.6 tha^{-1} (Nhamo *et al.*, 2003).

2.3 Climatic characteristics of semi-arid areas

Rainfall over southern Africa is associated with the movement of the Inter-Tropical Convergence Zone (ITCZ) (Dennett, 1987). Following the movement of the sun, the ITCZ and associated rainfall moves towards southern African countries during the October to November period. The intensity of the ITCZ and the resultant rainfall amounts over southern Africa are also influenced by topography and the El Niño-Southern Oscillation (ENSO) phenomenon (Hulme and Sheard, 1999; Clay *et al.*, 2003; Trenberth *et al.*, 2007). There is a significant relationship between the ENSO phenomenon and the inter-annual rainfall variability in some parts of southern Africa (Hulme and Sheard, 1999; Clay *et al.*, 2003). Regional sea surface temperatures (SST) and latitude also have an influence on rainfall patterns in southern Africa (Clay *et al.*, 2003). Under normal circumstances the ITCZ often moves between Tanzania and Zimbabwe and rarely goes beyond the Limpopo river in the south (Love *et al.*, 2008).

Rainfall, occurring as short duration, high intensity convective storms is confined to one distinct rainy season stretching from October to April (Unganai, 1996; Nonner, 1997). Generally the rainy season ends in March-April following the northward retreat of ITCZ and reduced heating of the continent (Tadross *et al.*, 2007). The high spatial variability of rainfall in semi-arid regions arises from its convective nature (Dennett, 1987). Typical coefficients of variation range from about 20 to 40 % in East Africa (Rockström *et al.*, 2003) and 34 to 44 % in semi-arid areas of Zimbabwe (Oosterhout, 1996; Chapter 4). Climatic variability is enhanced by climate change and

climatic phenomenon such as ENSO which increases the potential for drought occurrence (Dennett, 1987; Phillips *et al.*, 1998).

Statistically, complete crop failure in semi-arid areas due to droughts occurs almost once every 10 years (Rockström *et al.*, 2002). Analysis of rainfall data from stations in semi-arid NR V of Zimbabwe showed a high probability (once every five years) of crop failure for sorghum and pearl millet (Nyamudeza, 1998). A climatic study conducted by Unganai (1996) using Global Climate Models (GCM) revealed that, between 1900 and 1993, total precipitation over Zimbabwe declined by up to 10 % on average.

Analysis of rainfall data has shown that water-related problems in semi-arid tropics are often associated with intra-seasonal dry spells during critical stages of crop growth rather than cumulative rainfall (Rockström *et al.*, 2003; Oosterhout, 1996). For example, a study of five semi-arid districts in Zimbabwe by Oosterhout (1996) showed that years with the highest total rainfall did not coincide with years of highest crop yields. An earlier study by Unganai (1990) had indicated that approximately 480 mm of rainfall, well distributed throughout the growing season was sufficient for successful production of sorghum and maize crops.

Research in east Africa showed that the probability of occurrence of a dry spell of two to four weeks during the growing season far exceeds that of droughts (Rockström *et al.*, 2002). In Machakos (Kenya), where seasonal rainfall is bimodal findings by Barron (2004) indicated that the probability of occurrence of dry spells exceeding five days was higher for the long rains (90 %) than for the short rains (78 %). These dry

spells are detrimental to crop yields if their occurrence coincides with critical phases of crop development. In semi-arid regions, severe crop yield reductions due to dry spells occur once or twice in every five years (Rockström *et al.*, 2003).

The uncertainties and variability of rainfall in semi-arid tropics formed a basis for numerous studies on analysing the cropping seasons. In Zimbabwe, the anomalies and generalizations associated with the pioneering work on agro-ecological classification conducted by Vincent and Thomas (1960) has led to several reassessments. The Department of Agricultural Technical and Extension Services (AGRITEX, 1990) refined the classification by defining and mapping five agro-ecological regions based on rainfall amount, distribution and altitude (Fig. 2.1). In northern Zimbabwe agro-hydrological analysis of daily rainfall data from four stations (Binga, Kamativi, Bumi Hills and Siabuwa) by Chiduza (1995) revealed that within the same NR, some sites had a better cropping potential than others.

Despite advances in agroclimatology, forecast of seasonal rainfall distribution from early events such as onset of the rainy season remains uncertain. Dennett (1987) concluded that there is little evidence to suggest such relationships. Analysis of rainfall data provides important information for agricultural management in rainfed agriculture. The determination of start, end and length of a growing period, together with the frequency and duration of dry spells is useful to farmers and land use planners in crop selection, timing of farming activities and variety selection. By incorporating soil water characteristics and yield reduction factors, yield estimates also can be obtained (Barron, 2004).

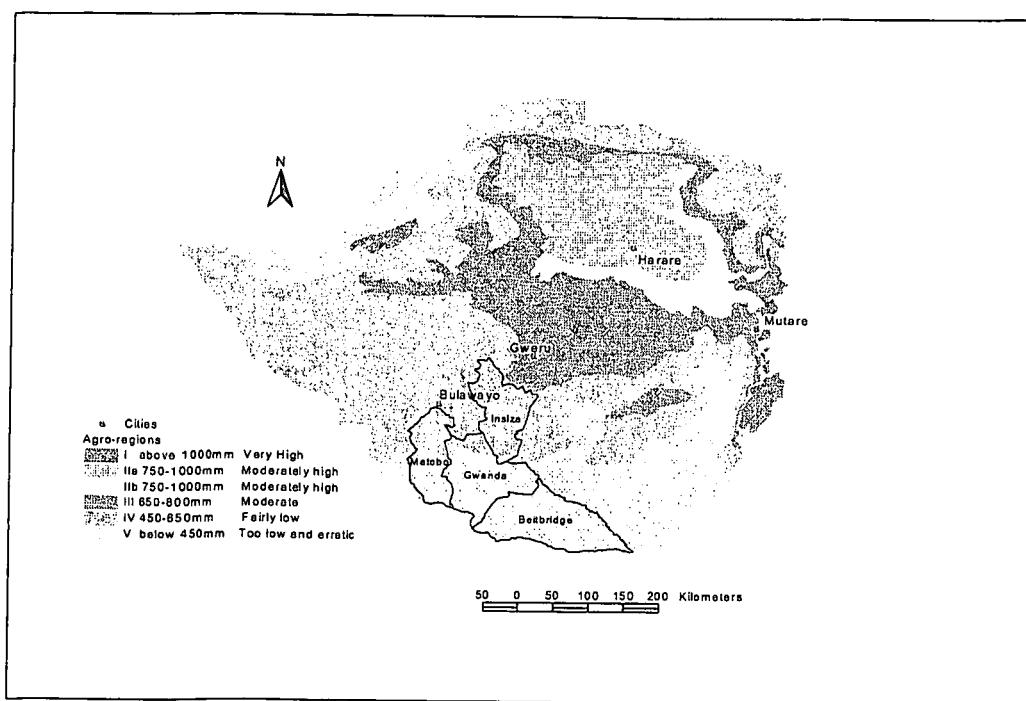


Figure 2.1. Agro-ecological regions of Zimbabwe (Source: ICRISAT GIS office, 2008)

An analysis of the amount and distribution of rainfall in NRs. II, IV and V of Zimbabwe showed that the growing season averages 96 days (Hussein 1987 in Morse 1996). In NR V the season starts in early December and finishes by 24 March (Morse, 1996). False start of growing season is a common feature in semi-arid areas as early rains are often followed by long dry spells before crop establishment (Dennett, 1987). Regression analysis of rainfall data by Hussein (1987 in Morse 1996) showed that the length of the growing season increased with earlier onset of the rainy season. At three semi-arid sites in Botswana, Kanemasu *et al.* (1990) observed a similar relationship ($R^2 = 0.76$) between onset and duration of rainfall. These climatic features of the area need to be considered when formulating recommendations for smallholder farming systems.

2.4 Tillage techniques and other *in situ* strategies

Good soil water management in rainfed agriculture can be achieved through various tillage methods, both conventional and reduced, and rainwater harvesting techniques or structures. Various researchers and development agencies have explored *in situ* rainwater harvesting. For upgrading rainfed agriculture in semi-arid tropics Rockström (2002) classified rainwater management methods into the following categories:

- (1) Systems that prolong the duration of soil moisture availability in the soil for example mulching practices;
- (2) Systems that promote infiltration of rainwater into the soil. These techniques include pitting, ridging or furrowing and terracing;
- (3) Systems that store surface and sub-surface runoff water for later use e.g. rainwater harvesting systems with storage for supplementary irrigation.

Soil tillage, to be defined as 'The manipulation, generally mechanical, of soil properties to modify soil conditions for crop production' (SSSA, 1987) has, through the ages been applied in farming systems where natural vegetation is replaced by arable crops. The majority of the soils (sands, loamy sands and sandy loam) in the drier regions of southern Africa are poorly structured, self compacting and have a tendency to crust. The primary functions of tillage in these areas are to prepare a seed bed, control weeds, incorporate crop residues and manures, enable water infiltration into the soil and permit the growth of roots down the profile, where soil water may be stored.

Throughout southern Africa the timing of primary tillage operations such that cultivation is done during the post-harvest autumn period has been advocated as a

sound practice, as weeds are destroyed (Willat, 1967), draught animals are still in good condition at the end of the growing season, and the soil surface is in a state which permits infiltration of the early spring rains. However, few smallholder households manage to achieve this post harvest ploughing, despite the obvious advantages on some soil types (Grant *et al.*, 1979; DLFRS, 1985). The reasons for this are many and varied, and include the fact that the soils are too hard to plough at the end of the season when dry, traditional practices in many areas is to allow livestock to graze crop residues *in situ* over the winter period, other household activities such as marketing of produce take priority in allocation of labour. To overcome the inability to carry out an autumn ploughing, work in Botswana clearly demonstrated the advantages of a double spring ploughing, increasing yields by as much as 71 % across a range of soil types (Table 2.1). Similar results have been observed in Zimbabwe for a range of soil types (Twomlow and Bruneau, 2000).

Table 2.1. Effect of double spring ploughing on sorghum grain yield for seven soil types in Botswana in 1988/89, after Heinrich 1989

Soil Type	Adjusted grain yields kg ha ⁻¹ at 10% moisture content						
	shallow ferric luvisol	shallow ferrallic arenosol	calci cambisol	orthic luvisol	deep ferric luvisol	cambic arenosol	luvic arenosol
Conventional ploughing	790	1996	1255	1059	606	1351	1365
Double spring ploughing	1020	2674	1369	1273	682	2812	1470

From recent studies of smallholder farmers in southern Africa it is clear that farmers already employ tillage practices with the aim of accomplishing several short-term goals including seedbed preparation, weed control and rainwater retention (Morse, 1996; Twomlow and Bruneau, 2000). In Zimbabwe, as in Tanzania, it has been reported that farmers recognise that timely inter-row cultivation is important for both

weed control and for maintaining a rough soil surface which can retain subsequent rainfall.

2.5 Soil water management in semi-arid smallholder farming systems

The water balances can be formulated at different spatial scales (soil, field, farm, catchment, basin) and temporal scales (days, weeks, decade, season, year). As shown by field studies conducted by Klaij and Vachaud (1992) and Verplancke (1994) in the Sahel region (Niger), water balance analysis is important for rainwater management in rainfed cropping systems. It can be used to determine the effect of management systems on rainfall partitioning. The results are useful for adapting crop growth to water availability in the soil. In rainfed systems, the water balance can be formulated thus:

$$P + R_{on} = ET + R_{off} - (C-D) \pm \Delta SW \quad \text{Equation 2.1}$$

where

P = Precipitation (mm)

R_{on} = Surface runoff into field (mm)

ET = Evapotranspiration (mm)

R_{off} = Surface runoff out of the field (mm)

C = Capillary rise (mm)

D = Deep percolation (drainage) (mm)

ΔSW = Change in soil water over the considered time (mm).

Techniques that capture rainwater, reduce surface runoff and promote infiltration have traditionally been used in Africa (Reij *et al.*, 1996). In sub-Saharan Africa these techniques include planting pits, infiltration pits, terracing, mulching, stone bunds and ridges/furrows (Hudson, 1987). Elsewhere in Africa other systems exist such as the *Trus* system in Sudan, the *Zai* system in Mali and Burkina Faso, and the *Tassa* system in Niger (Mandiringana *et al.*, 2003). In South Africa extensive research work has been conducted on runoff in-field rainwater harvesting using basins and mulch under semi-arid conditions (Botha *et al.*, 2003) and used by smallholder farmers in marginal areas with maize and a variety of vegetables.

In Zimbabwe, water management under rainfed cropping systems has been the focus of several field studies, encompassing the effects of cereal-legume rotations on soil water (Ncube, 2007), weeding effects on soil water regimes (Twomlow and Bruneau, 1998), tillage effects on soil water dynamics and crop yields (Nyamudeza, 1993; Nyakatawa *et al.*, 1996; Nyagumbo, 2002), tillage effects on weeds (Dhliwayo *et al.*, 1995, and soil erosion control (Chuma, 1993; Chuma and Haggmann, 1998; CONTILL, 1998). AGRITEX through the Lowveld Research Stations, Cotton Research Institute, Makoholi Experiment Station and Agronomy Institute conducted numerous studies on soil and water conservation systems from the mid-1980s.

At Matopos Research Station, Ncube (2007) monitored the residual soil water benefits of four grain legumes (bambara nuts, cowpea, groundnut and pigeon pea) to sorghum in a legume-sorghum rotation over three cropping seasons. Results from that study showed that soil water dynamics in the 0 - 0.25 m soil layer during the sorghum growing phase of the rotation depended on rainfall pattern and not the previous

legume crop. However, soil water content differences between the grain legumes were observed in the 0 - 0.55 m profile of the sandy soil at the experimental site.

Improved soil water supply, rooting depth and crop yields through use of minimum tillage techniques have been reported in semi-arid regions of Zimbabwe (Nyamudeza, 1993, Vogel, 1993). On sandy soils at Chivi (NR V) and Matibi I (NR IV) Nyakatawa *et al.* (1996) observed a 22 - 85 % increase in maize yields due to tied furrows compared to the farmers' practice of planting on the flat. The response was low for sorghum with an average yield increase of 18 %. The yield increase rose to 35 - 115 % and 59 - 200 % for maize and sorghum respectively by adding inorganic fertilizer although the interaction was not significant. On a sandy clay loam soil at Chiredzi Research Station, tied furrows increased sorghum yield by 4 - 62 % in 4 out of 5 seasons compared to the farmer's practice of sowing on the flat (Nyamudeza, 1993). In a very wet year, Nyamudeza *et al.* (1992), working on vertisols in south eastern Zimbabwe, reported that tied furrows did not significantly affect sorghum yields in years with adequate rainfall. Crop response to tied furrows and fertilizers was affected by rainfall distribution within the season rather than total annual rainfall. In all cases, significant increases in grain yields were observed in seasons with mediocre or good rainfall distribution. Droughts and poorly distributed rainfall resulted in no positive response to either tied furrows or fertilizers, forcing farmers to revert to their old production practices.

The presence of crop residue mulch at the soil-atmosphere interface has a direct influence on infiltration of rainwater into the soil and evaporation from the soil. Trials conducted in the higher potential areas of Zimbabwe between 1988 and 1995

indicated that mulching significantly reduced surface runoff and hence soil loss (Erenstein, 2002). Mulch cover shields the soil from solar radiation thereby reducing evaporation losses from the soil surface. Soil biota increase in a mulched soil environment thereby improving nutrient cycling and organic matter builds up over a period of several years (Holland, 2004).

On a sandy loam soil in semi-arid Kenya, studies by Gicheru *et al.* (2003) revealed that a combination of 3 t ha^{-1} mulch cover and 3 t ha^{-1} manure promoted more recharging of soil profiles with water under minimum tillage than conventional ploughing. Nyagumbo (2002) monitored the effect of mulch ripping, no-till tied ridging and conventional tillage on recharge of groundwater on a red clay soil. Mulch ripping reduced surface runoff and resulted in higher soil water content in the top 0.45 m of the soil profile.

Bescansa *et al.* (2006) in semi-arid parts of Spain compared the effect of combining surface mulch with zero tillage and conventional ploughing on soil water retention. Results from that study showed development of more soil pores (6 - 9 μm pore diameter) for water storage in the top 0.15 m of the soil profile under no-till plus mulching. Conventional ploughing had pores predominantly greater than 9 μm which are good for soil water drainage under gravity. Under any given suction, soil under no-till with mulch cover retains more soil water than under conventional tillage suggesting soil structural improvement (Bhattacharyya *et al.*, 2006)

Excessive weed growth has been identified as one of the major factors limiting crop production in smallholder farming systems of Zimbabwe (Dhliwayo *et al.*, 1995).

Field studies have shown that weed transpiration has a profound impact on soil water regimes in semi-arid environments (Van der Meer, 2000). Thus apart from *in situ* rainwater harvesting through tillage practices, weed control is an important water conservation practice. Besides reducing unproductive water flows through weed transpiration, weed control also reduces competition for nutrients and radiation between crops and weeds. In an assessment of eight hand weeding treatments at Makoholi Experiment Station (Masvingo in Zimbabwe), Twomlow *et al.* (1997) reported that the control treatment (no weeding) had the driest soil profiles and lowest maize yields. The weed free treatment had a significantly wetter soil profile than the other 7 treatments. Studies conducted by Shumba *et al.* (1992) at Matopos and Makoholi also showed that early weeding resulted in 40 % more maize grain than the farmers' practice (control). The study also showed significant weeding x nitrogen interaction effects on maize yields. Twomlow and Bruneau (1998) reported that crop yields would be reduced if weed control is inadequate, even when water conservation measures such as tied ridges are used. They therefore, concluded that weed management is critical for maximizing soil water availability for crop growth.

Despite the role of *in situ* rainwater harvesting systems in improving water availability to crops, their potential to mitigate dry spells and other problems of yield reduction appears limited, especially on sandy soils characterized by low inherent water holding capacity. In semi-arid Machakos district of Kenya smallholder farmers cited insufficient rainfall as the major reason for low crop yields (Barron and Rockström, 2003), suggesting that water deficits are still being experienced. In addition, most studies on *in situ* rainwater harvesting systems overlooked the problem of soil fertility, which can curtail the benefits associated with improved soil water

status. Exceptions are studies by Nyakatawa *et al.* (1996) which investigated the interaction of tied ridge/furrow system and soil fertility.

2.6 Soil fertility management in semi-arid smallholder farming systems

Continuous cropping without addition of nutrients and organic matter is a major threat to sustainable crop production in sub-Saharan Africa (Waddington *et al.*, 1994). Unlike the effects of water stress due to droughts and dry spells, the effects of low and declining soil fertility on crop yields are gradual. In Zimbabwe, most soils found in the communal areas are sands, derived from granitic parent material (Grant, 1981). The soils have low inherent fertility, poor water holding capacity and low organic matter (Grant, 1981). In Africa it is reported that nitrogen (N) is lost at a rate of more than 30 kgNha⁻¹year⁻¹ from the smallholder cropping systems (Hikwa *et al.*, 2001). Over a period of five years, Plucknett (1994) reported a 21 and 14 % decline in soil organic carbon and phosphorus. Due to rapid population growth and limited arable land, traditional soil fertility management practices such as shifting cultivation are no longer feasible (Müller-Sämann and Kotschi, 1994).

A soil fertility mapping study involving 3 500 smallholder farmers in Zimbabwe during 1994/5 and 1999/2000 seasons showed that N and P were limiting in 70 % of the soils (Hikwa *et al.*, 2001). An assessment of nutrient status of 250 soil samples submitted to Soil Analysis Laboratory of the Chemistry and Soil Research Institute revealed serious N deficiencies in 82 % of the soil samples (Nyamangara *et al.*, 2000). Mapfumo and Mtambanengwe (1998) reported similar results in a survey of ten smallholder farm sites dominated by continuous maize cropping systems. In the same

study by Mapfumo and Mtambanengwe (1998), nutrient losses through removal of crop residues accounted for 44 % of the N losses from the cropping system.

Despite the low and declining soil fertility, inorganic fertilizer use in smallholder farming systems is low. A survey conducted in semi-arid Chivi district (NR V) of southern Zimbabwe showed that 59 % of smallholder farmers did not apply fertilizer or manure (CIMMYT, 1993). In 1983, it was estimated that inorganic fertilizer use under smallholder cropping systems in Sub-Saharan Africa was about 5 kg ha⁻¹ (Plucknett, 1994), while in Zimbabwe, a country with a high fertilizer use by 1983, average rates monitored by CIMMYT (1993) during the 1992/93 season were 30 kg N ha⁻¹ and 10 kg P₂O₅ ha⁻¹ in NR IV and 12 kg N ha⁻¹ and 3 kg P₂O₅ ha⁻¹ in NR V. The decrease in rates from NR IV to the drier NR V was attributed to variability of rainfall, which makes investment in fertilizers risky. Fertilizer application was higher when government or Non-Governmental Organizations (NGOs) provided free fertilizer. At Beitbridge, a participatory rural appraisal (PRA) conducted by the South Eastern Dry Areas Project (SEDAP) (2001) highlighted that farmers did not consider soil fertility a problem in their farming system. Accordingly, a follow-up focused diagnostic survey showed that only 5 and 7 %, of smallholder farmers in Gwanda and Beitbridge districts respectively used fertilizers (Nyamudeza, *pers. com.*). A similar trend was observed by Nyamudeza *et al.* (*pers. com.*) in a survey of five districts in NRs IV and V. A survey conducted by ICRISAT in southern Zimbabwe revealed that 40 % of the interviewed farmers acknowledged declining soil fertility as a problem (Ahmed *et al.*, 1997).

As soil fertility in smallholder farming systems continues to decline the problem is further aggravated by inherent low fertility of some of the soils and low fertilizer inputs. Nutrient balance analysis provides a basis for maintaining soil fertility (Archer, 1988) and is crucial for identifying unsustainable land use systems (Bindraban *et al.*, 2000). A positive nutrient balance indicates an improvement in soil fertility. Sahel studies have shown that smallholder farming systems lack the internal capacity to replenish nutrient losses due to crop biomass off take for use by the livestock part of the farming system (Powell *et al.*, 1996). As a result nutrient balances with regards to N are negative in most cases (Bosch *et al.*, 1998). However, few field studies have been conducted to determine the nutrient balances and fluxes in smallholder farming systems. Pilbeam *et al.* (2000) attributed this lack of studies on nutrient balances to difficulties in quantifying some of the components (for example leaching and gaseous losses of nitrogen). Attempts to quantify all nutrient inflows and outflows include lysimeter studies (Archer, 1988; Haggmann, 1994) and ^{15}N isotope analysis (Archer, 1988).

Studies have shown that in drought-prone environments, crop response to fertilizer is highly dependent on seasonal distribution of rainfall (Shumba *et al.*, 1992; Nyakatawa *et al.*, 1996; SEDAP, 2001). Fertilizer recommendations for semi-arid areas of Zimbabwe have been based on research conducted in low-risk high rainfall areas. In some cases, farmers' experiences with inorganic fertilisers have not been encouraging due to lack of knowledge and skills in using inorganic fertilisers (Lee, 1993) resulting in crop burn, lack of response and high labour costs. In some remote semi-arid areas, farming inputs including fertilisers are difficult to access when required. Investment of scarce resources into inorganic fertilisers is therefore risky particularly at the

current recommended rates of 300 kg ha⁻¹ ammonium nitrate (34.5 % N) and 300 kg ha⁻¹ compound D (8 % N, 14 % P₂O₅, 7 % K₂O).

2.7 Water use efficiency in semi-arid smallholder systems

Agricultural productivity in arid (precipitation/potential evapotranspiration < 0.2) and semi-arid (0.2 < precipitation/potential evapotranspiration < 0.5) environments is limited by water availability (Debaeke and Aboudrare, 2004). Greater water use efficiency can be achieved through elimination of biophysical and socio-economic constraints facing smallholder farmers. In smallholder agriculture these constraints include timely planting and weed control, labour availability, balanced soil nutrient management, use of recommended crop type and varieties, and availability and accessibility of farming inputs to farmers.

In rainfed smallholder agriculture timely planting is crucial in order to make full use of early rains in the season. Late planting at times leads to no crop harvests as seasons end abruptly. Weed control is probably the greatest challenge in improving water use efficiency in semi-arid cropping systems. Weed transpiration leads to more rapid depletion of soil water thereby exposing crops to severe soil water stress during dry spells or drought (Van der Meer, 2000). Studies conducted at Makoholi Research Station (NR IV) of Zimbabwe revealed that weeding at 2 and 6 weeks after maize crop emergence significantly increased water use efficiency compared to 4 weeks after emergence (Twomlow and Dhliwayo, 1999). Maize (*Zea mays* L.) water use efficiency increased from 3.9 to 5.0 kg ha⁻¹ mm⁻¹ with two weedings (at 2 and 6 weeks after crop emergence) compared to one weeding at 4 weeks after emergence.

Balanced soil nutrient management ensures efficient use of soil water at each stage of crop growth (Bouman, 2007). Adequate soil nutrient supply promotes early development of crop canopy leading to better interception of solar radiation which in turn increases root development and allocation of root-extracted water to transpiration (Sivakumar and Salaam, 1999). In semi-arid West Africa application of 30 kgNha^{-1} and $45 \text{ kgP}_2\text{O}_5\text{ha}^{-1}$ increased both yield and water use efficiency of pearl millet (Sivakumar and Salaam, 1999). Studies by Ncube (2007) showed that maize yields and water use efficiency can be significantly increased by application of small rates of manure (3 tha^{-1}) and N (10 kgNha^{-1}) in a semi-arid environment where farmers do not traditionally use the two nutrient inputs.

2.8 Current risk mitigation strategies in semi-arid southern Zimbabwe

Efforts to reduce the impacts of drought and dry spells are underway in the semi-arid regions of sub-Saharan Africa. The current initiatives aim at harvesting rainwater, and managing soil water and fertility on smallholder farms. This will lead, hopefully, to a reduction in the risk of total crop failure, improve water productivity and crop yields. Several international and national organisations are spearheading the spread of technologies that have shown potential for semi-arid smallholder agriculture. International organisations such as ICRISAT and CIMMYT, NGOs such as World Vision, Catholic Development Commission (CADEC) and Practical Action are all taking part in the development activities sponsored by Department for International Development (DFID) and European Commission Humanitarian Organisation (ECHO) (Twomlow *et al.*, 2006b). The development work is taking a participatory approach giving the smallholder farmers and extension officers an equal-partner-status at all stages of the activities in their communities.

Water management techniques at a field scale in semi-arid southern Zimbabwe include ordinary contours, dead level contours with underground storage tanks and infiltration pits (Mwenge Kahinda, 2004; Mupangwa *et al.*, 2006). *In situ* water management techniques include planting basin tillage and deep winter ploughing soon after crop harvest. The microcatchment structures include dead level contours with or without infiltration pits (Plate 2.1) and ordinary contour ridges ($< 5\%$ slope). Between the fields dead level contours harness water originating from the area upslope. The dead level contours vary in size, the minimum having a cross-sectional dimension of 1.5 m width and 0.5 m depth (Mwenge Kahinda, 2004). The length of each contour varies according to the length of the field. Currently soil water and crop yield benefits derived from dead level contours with or without infiltration pits have not been quantified.



Plate 2.1 Dead level contours with storage tanks and infiltration pits in ward 17 of Gwanda district

The promotion of *in situ* water management techniques such as planting basins and ripper tillage systems began during the 2004/05 cropping season in eight districts of semi-arid Zimbabwe. The program was built upon the seed and fertilizer relief

program sponsored by DFID (Twomlow *et al.*, 2006b). Officials from AGRITEX and NGOs received training on concepts of conservation agriculture. The initial training workshop had a strong practical focus with participants being trained in site selection, laying out demonstration plots with emphasis being placed on spacing, digging the basins, fertilization, planting and weeding. Results from paired plot demonstrations (planting basins against conventional ploughing) showed an increase ($P < 0.001$) in cereal yields through the use of planting basin tillage across five of the eight districts (Twomlow *et al.*, 2006a). The significant cereal yield increase was attributed to timeliness of planting and better management of planting basin system compared to conventional practice. For the semi-arid southern Zimbabwe environments, simulation modelling using Agricultural Production Simulator (APSIM) showed that combining rainwater harvesting technologies with organic and inorganic fertilizers could reduce the risk of crop failure from 20 to 7 % (Mwenge Kahinda, 2004).

The drip irrigation technology was introduced to improve household food security and incomes in semi-arid communities (Moyo *et al.*, 2006). The United States Agency for International Development (USAID) funded program was introduced with the aim of reducing the negative impact of water shortages and increase productivity of the available limited water resources. Moyo *et al.* (2006) assessed the sustainability of drip irrigation in home gardens in Gwanda and Beitbridge districts of southern Zimbabwe. The study revealed that beneficiary farmers encountered challenges that included availability of adequate water during the dry season, availability of drip kit spare parts and lack of technical back up support during the use of the drip kits. Only 5 % of the beneficiary farmers in Beitbridge district had used their kits at the time of study by Moyo *et al.* (2006). In Beitbridge 49 % of the water sources available for

drip-irrigated farming had dried up when the survey team visited the district in February 2004 while Gwanda district had lost 5 % of its water sources (Moyo *et al.*, 2006). Lack of co-ordinated approach by relevant stakeholders negatively impacted on the sustainability of the drip irrigation programme.

A review of literature from Zimbabwe and other southern African countries shows that technologies have been developed for improving crop and water productivity under rainfed smallholder farming conditions. Currently the planting basin and ripper tillage systems, and dead level contours are being promoted in semi-arid southern Zimbabwe. However, technical information on the contribution of these soil water management technologies is still lacking. Integration of the soil water and fertility management is a potential key to improved soil and crop productivity in the smallholder farming system. This study focuses on quantifying soil water derived from *in situ* and between-field rainwater management practices for drought mitigation in water-scarce environments such as the Mzingwane catchment of the Limpopo Basin. The study goes further and explores the effect of integrating soil water and fertility management practices on crop yield under semi-arid smallholder farming conditions as well as documenting the farmers' opinion of the interventions.

CHAPTER 3

General Materials and Methods

3.1 Site descriptions

3.1.1 On-farm sites

Insiza and Gwanda districts lie in the Mzingwane catchment which is part of the Limpopo river basin. Insiza district lies in NR IV which is characterized by semi-arid climatic conditions with total annual rainfall ranging between 450 and 650 mm (FAO, 2006). Gwanda district lies in NR V which receives annual rainfall of less than 450 mm. In both districts, the rainfall season is unimodal and begins in November/December and ends in March/April. The cropping season experiences periodic dry spells particularly in January and is followed by a cool to warm dry season from May to September.

The predominant soils in Insiza and Gwanda districts are coarse-grained sands to loamy sands and clay loams to clay with minor occurrences of vertisols (Anderson *et al.*, 1993). The soils are classified as 2, 4P and 5G according to the Zimbabwe Soil Classification system, Eutric/Dystic Regosols and Chromic Luvisols according to FAO/UNESCO classification, and as Ustalfic Haplargid and Lithic/Ustic Torriorthent according to Soil Taxonomy (Nyamapfene, 1991; FAO, 2006). Landform is almost flat to undulating pediplain with some local hills and rock outcrops. Vegetation consists of *Colophospermum mopane* as the dominant tree species with scattered associated tree species of *Commiphora spp*, *Combretum apiculatum* and *Adonsonia digitata*.

3.1.2 On-station sites

Matopos Research Station lies at 28°30.92'E, 20°23.32'S and 1 344 m above sea level. Lucydale experimental site lies at 28°24.46'E, 20°25.64'S and 1 378 m above sea level. Matopos Research Station is located in NR IV, which is characterized by semi-arid climatic conditions and rainfall season is unimodal and begins in November/December and ends in March/April. The long-term average rainfall for Matopos and Lucydale is 590 mm (Ncube, 2007). As in Insiza and Gwanda districts, the cropping season at Matopos and Lucydale also experiences periodic dry spells particularly in January. The cool period stretches from May to August with a rise in temperatures experienced as from September.

The red clay soil at Matopos Research Station is classified as a siallitic soil (4E.1) and Chromic-Leptic Cambisol according to the Zimbabwean and FAO systems (Moyo, 2001). The internal drainage of Matopos clay soil shows signs of saturation for short periods during the rainy season and external drainage is characterised by slow surface runoff (Moyo, 2001). The granitic sand at Lucydale is classified in the Zimbabwean system as moderately deep to deep well-drained fersiallitic soil (5G.2) (Nyamapfene, 1991) and is classified as Eutric Arenosol by FAO (1998). The chemical and physical properties of the two soil types are described in Table 9a.2.

3.2 Focus group discussions and resource flow mapping

3.2.1 Focus group discussions

The first focus group discussions were conducted in Gwanda and Insiza districts of Matebeleland South province of Zimbabwe in March 2006. The researchers first sought permission from the District Administrators of Gwanda and Insiza districts so

that meetings could be held with farmers. After permission was granted, dates for the resource mapping were agreed upon with farmer representatives. In Insiza district farmers who participated in the focus group discussions were drawn from Mpumelelo and Masiyepambili villages (Plate 3.1). In Gwanda district participants came from Fumukwe, Humbane, Magaya, Mnyabezi D and Mnyabetsi S villages of ward 17 (known as Manama). Experimental details and results for soil water and fertility management assessment are presented in Chapter 5.

The focus group discussions held at the end of 2007/08 growing season aimed at evaluating the performance of single and double ploughing, ripping and planting basin tillage systems with farmers who were hosting the experiments. Two focus group meetings were convened, one in ward one of Insiza district and another in ward 17 of Gwanda district (Plate 3.1). The initial intention was to convene a third focus group meeting with farmers who had been practicing single conventional ploughing and planting basin tillage systems in Matobo district. However, this could not take place because of the prevailing political situation in Zimbabwe between March and July 2008. The experimental details and results for the evaluation of technologies are presented in Chapter 6. A checklist of guiding questions used during the focus group discussions is given in Appendix 6.1.



Plate 3.1. Focus group discussions in progress at (a) Humbane and (b) Mpumelelo villages of Gwanda and Insiza districts

3.2.2 Resource flow mapping

At the end of the 2005/06 growing season six farms hosting field based research trials were visited and the flow of agricultural resources was mapped on each farm. Four farms that were not hosting research trials were also visited and mapped during the same week. At the end of 2007/08 nine farms hosting research trials were visited and flow of agricultural resources was mapped (Plate 3.2). Out of the nine farms hosting trials three farms had not been visited at the end of 2005/06 growing season. Two of the four farms without research trials were revisited also at the end of 2007/08 season, the other two could not be visited because family heads were not available at the time of the resource mapping exercise. The experimental details and results are presented in Chapter 6 and names of participants are given in Appendix 6.2.



Plate 3.2 (a) Mrs. Sibanda of Mnyabezi D village of Gwanda district drawing her field map on the ground and (b) ICRISAT researchers interviewing Mr. Siza Mguni of Insiza district in April 2008

3.3 Rainfall analysis

3.3.1 Meteorological stations

Five meteorological stations that lie within the semi-arid southern Zimbabwe were selected for analysis of daily rainfall data collected over varying periods. The stations were considered because they lie within the Mzingwane river subcatchment and districts with sites for agronomic trials conducted in our study (Fig. 3.1). Daily rainfall data were obtained from the Zimbabwean Department of Meteorological Services. The different locations of the meteorological stations and their geographical descriptions are shown in Table 3.1. The rainfall analysis details and results are presented in Chapter 4.

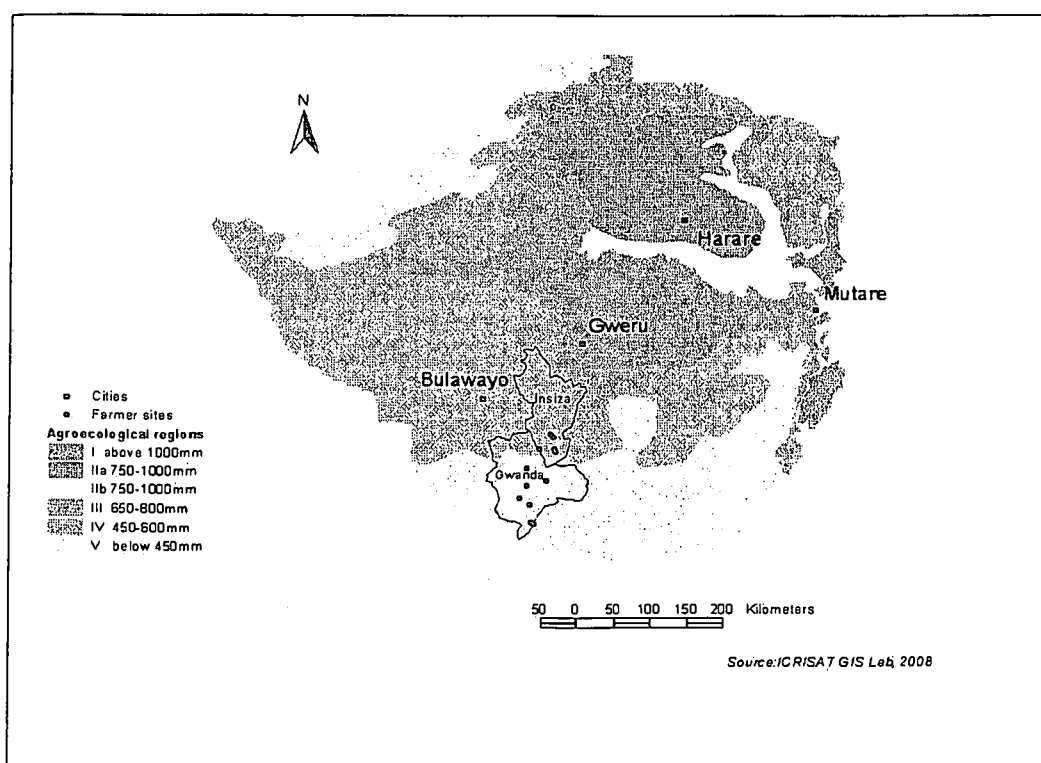


Figure 3.1 Agro ecological regions of Zimbabwe and location of experimental sites in Insiza and Gwanda districts, Matebeleland South province

Table 3.1. Geographical description of meteorological stations and rainfall database of the five stations used in the analyses

Station	Latitude	Longitude	Data period	Duration of data set
Bulawayo	-20.22	28.62	1930-2001	71
Matopos	-20.38	28.50	1939-2008	69
Mbalabala	-20.35	28.95	1931-1994	64
Filabusi	-20.55	29.28	1921-1995	74
Beitbridge	-22.22	30.00	1951-2001	50

3.4 On-farm experiments

3.4.1 Seasonal rainfall

For the on-farm experiments, each farmer was provided with a plastic raingauge for measuring daily rainfall (Plate 3.6). Farmers were first trained by ICRISAT researchers on how to use the plastic raingauge correctly and keep the rainfall records. Each farmer was provided with a book for keeping records of rainfall and agronomic

activities on the experimental fields and the record books were collected by ICRISAT researchers at the end of each season.

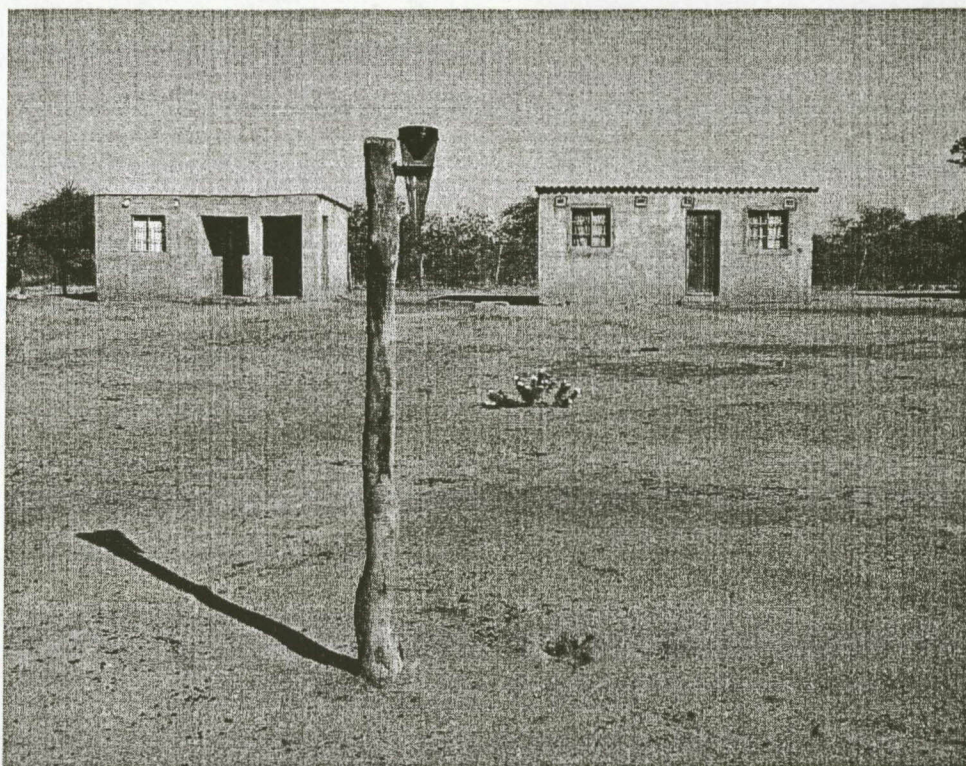


Plate 3.6. An ordinary raingauge installed at Mr. John Ncube's homestead in Fumukwe village of ward 17 (Manama), Gwanda district

3.4.2 Farmer selection

3.4.1.1 Insiza district

The host farmers for the research plots were chosen from a group of farmers that had been formed by World Vision for the Conservation Agriculture programme. Each farmer had a field that was fenced, accessible, had uniform soil type and adequate land to host the research trials. Three farmers namely Mpofu, Moyo and Nkomo hosted the trials in the first season. The number was increased from three to seven in the 2006/07 growing season. The seven farmers were drawn from Masiyepambili, Mpumelelo and Thandanani villages of ward 1 and the same farmers were maintained

in 2007/08 growing season. The names of the farmers who hosted the experiments are given in Appendix 7.1.

3.4.1.2 Gwanda district

Two groups of farmers were selected in ward 17 (also known as Manama) to host the two experiments that were run in the district. The farmers who hosted the tillage and nitrogen management experiment were selected based on land availability, soil type uniformity, accessibility and protection of field site. Three farmers namely Sibanda, Siziba and Ncube hosted the trials in the 2005/06 season and the number was increased to seven in 2006/07 growing season and then retained in 2007/08. Farmers were spread over four villages namely Mnyabezi D, Mnyabetsi S, Fumukwe and Magaya of ward 17. The farmers who hosted the second experiment, which was quantifying the soil water supply from dead level contours, were chosen by village representatives of the rainwater harvesting project that is being promoted in ward 17 by Practical Action.

3.4.2 Experimental layout

3.4.2.1 Experiment 1

The experiment consisted of four tillage treatments that were combined factorially with three nitrogen application rates. The four tillage treatments were hand dug planting basins (Basins), tine ripping (Ripper), single (CP) and double (DP) ploughing (Plate 3.4). The three nitrogen rates were 0, 10 and 20 kgNha⁻¹ applied as ammonium nitrate (34.5% N). The experiment was established at five farms in the 2005/06 growing and the number of farms was increased to 14 farms in 2006/07 season. The

14 farms used in the 2006/07 growing season were maintained in the 2007/08 season.

The experimental details and results are given in Chapter 7.

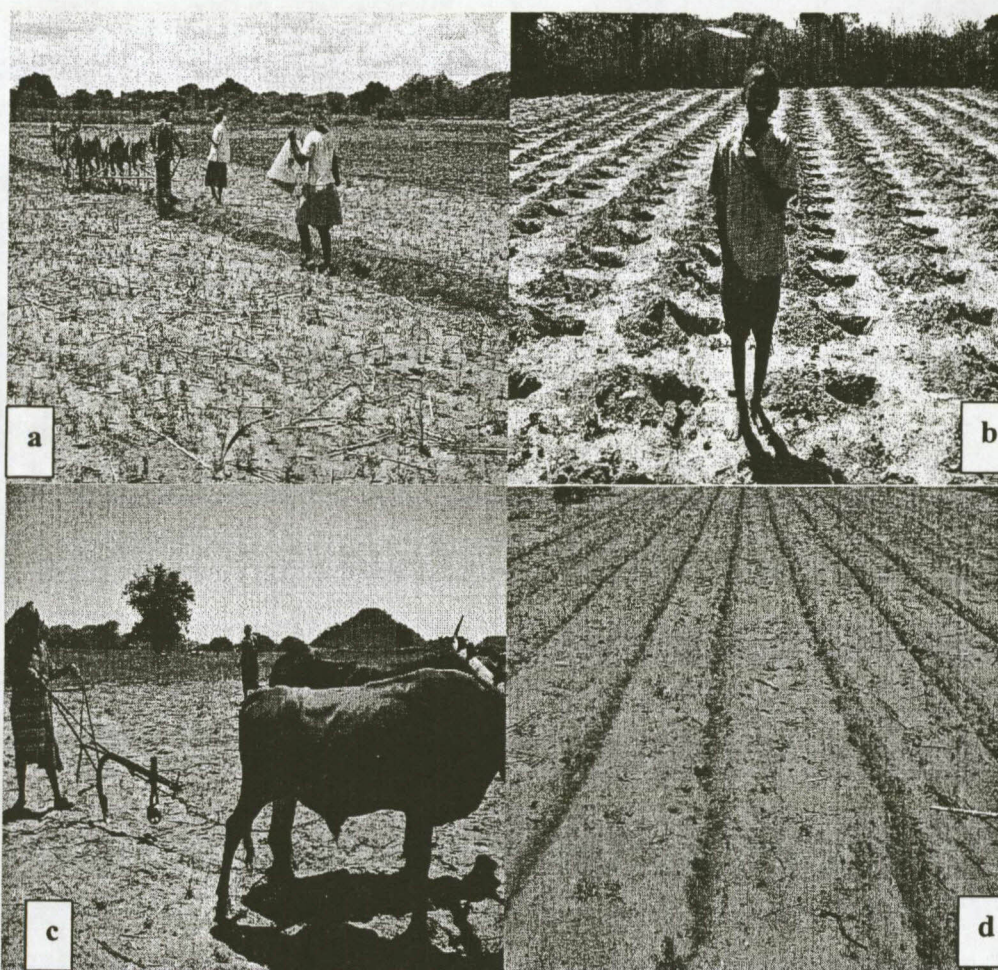


Plate 3.4. (a) Conventional ploughing (b) hand dug planting basins (c) ZimPlow ripper tine used for ripping tillage treatment at on-farm and on-station experimental sites and (d) Rip furrows opened by donkey/ox drawn ripper tine

Surface runoff was measured at four farms during 2006/07 and 2007/08 growing seasons. Runoff plots measuring 10 m x 10 m were established for each tillage treatment at each farm (Fig. 3.2). Each farm had a total of four runoff plots corresponding to each of the four tillage treatments. The boundaries of the runoff plots were constructed using a heat resistant black polythene plastic that prevented water flow from other parts of the field onto the runoff plot. At the down slope side of

each runoff plot a triangular surface of dimensions 10 m x 1.7 m was used to receive runoff water from the plot and lead it into 210 litre drum through a polythene plastic gutter.

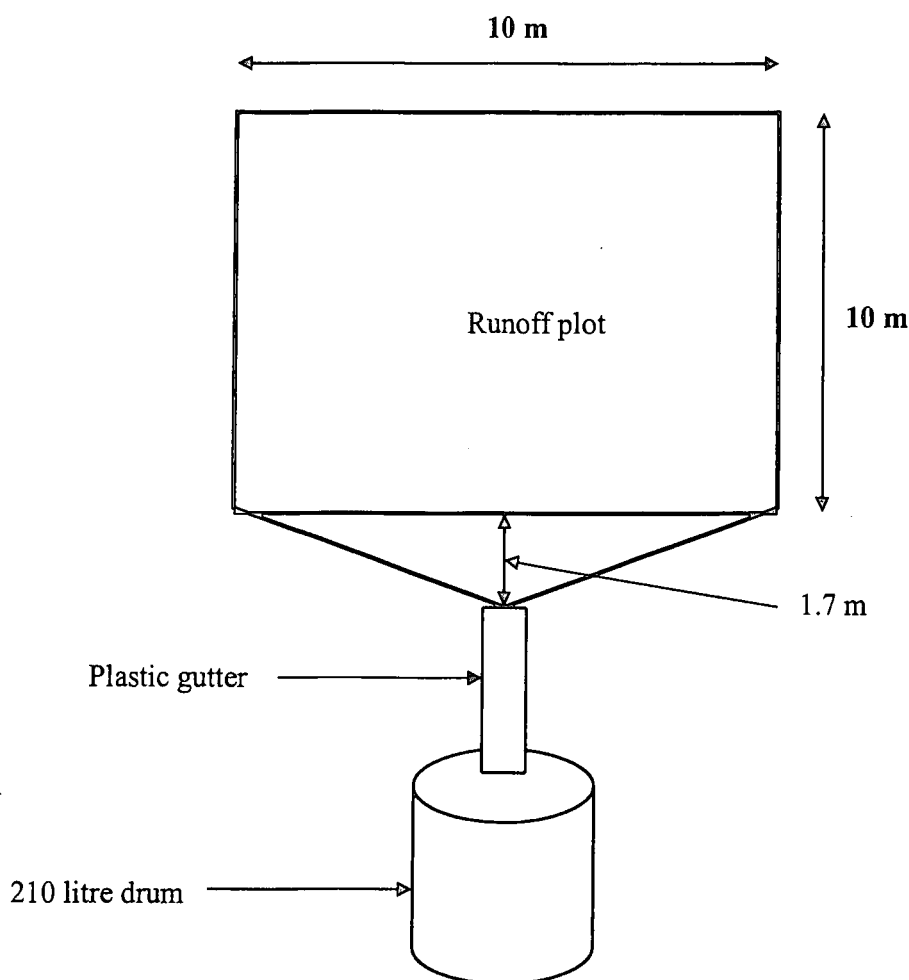


Figure 3.2. Schematic diagram of the set up of equipment for collection of runoff water from the plots under single and double conventional ploughing, ripper and basin systems

3.4.2.2 Experiment 2

This experiment consisted of a transect of access tubes across dead level contours with and without infiltration pits in Gwanda district (Plate 3.5 and Fig. 3.3). In the 2006/07 season one transect of six access tubes, two upslope and four downslope of the dead level contour were installed for soil water monitoring. In the 2007/08 season,

a second transect was established in order to separate the effect of conventional tillage from that of dead level contours on soil water content measured in the field. The area around access tubes of the second transect was left undisturbed and no crop was planted along this unploughed transect throughout the growing season. On the downslope side of contour access tubes were installed at 3, 8, 13 and 18 m from the centre of the dead level contour. On the upslope side of the contour access tubes were installed at 2 and 7 m from the centre of the contour. Weeds around access tubes of the second transect were controlled by spraying gramoxone herbicide. Further details and the results of this experiment are presented in Chapter 8.

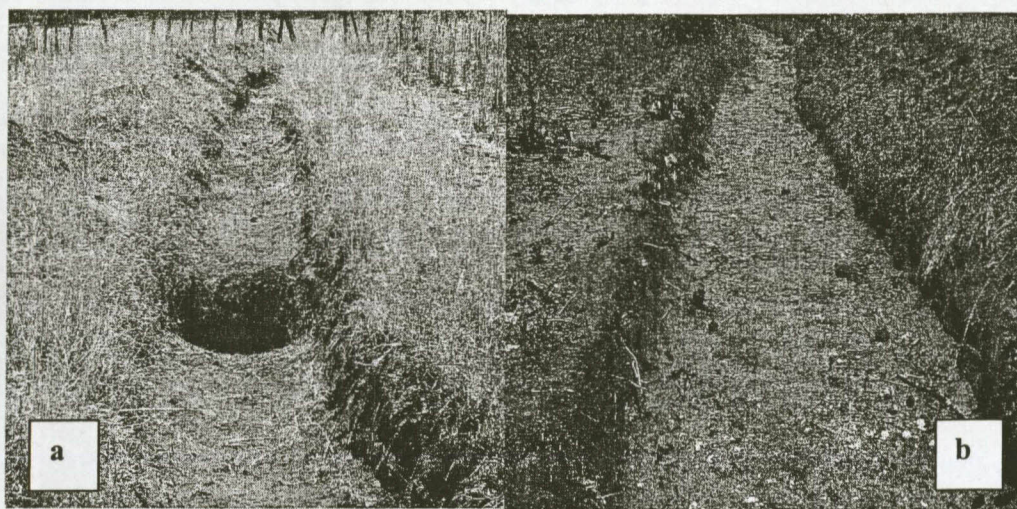


Plate 3.5. Dead level contour with (a) and without (b) infiltration pit in ward 17 of Gwanda district

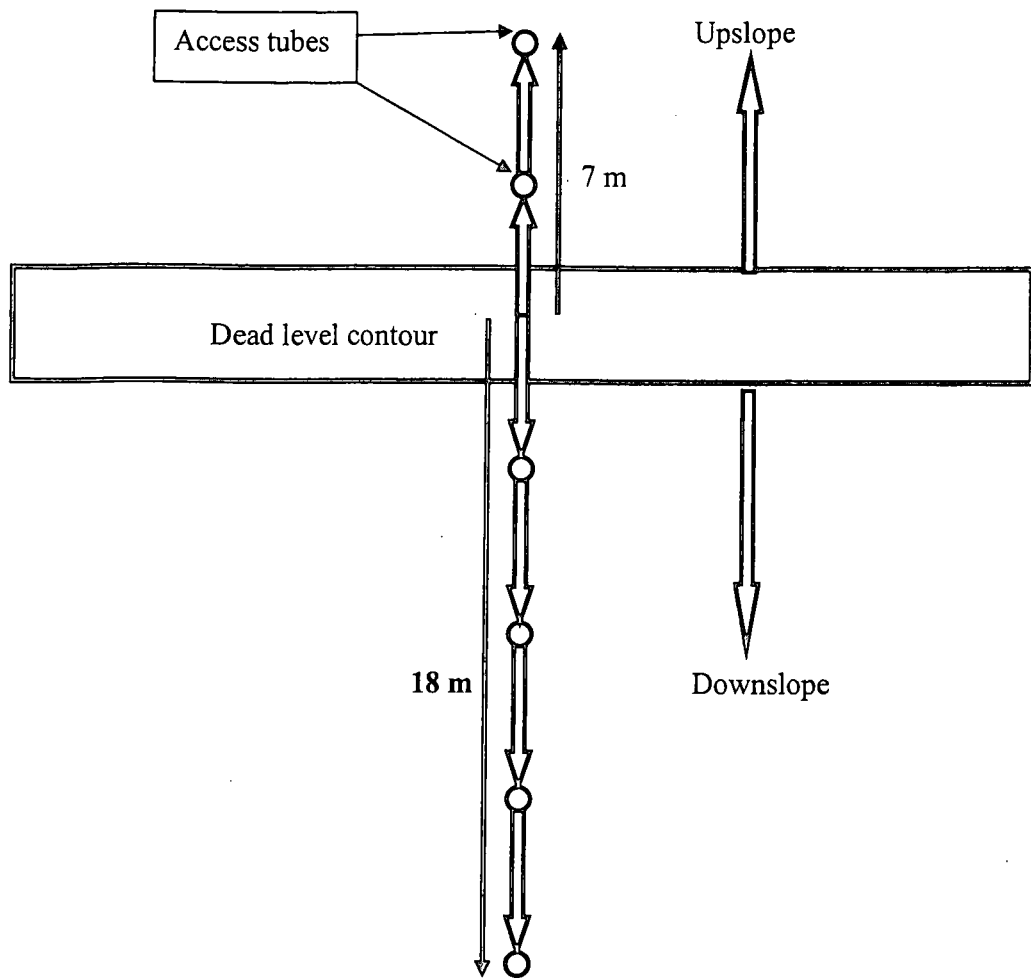


Figure 3.3. Schematic diagram of the set up of access tubes across dead level contours in Gwanda district

3.6 On-station experiment

3.6.1 *Experimental layout*

The experiment was run for two growing seasons at the Lucydale sandy soil site and four seasons at the Matopos clay soil site. At the Lucydale site, the experiment was run during 2004/05 season and the 2005/06 growing season. At the Matopos site, the experiment was run from the 2004/05 season to 2007/08 growing season. The experiment consisted of three tillage treatments, namely conventional ploughing, ripper and planting basins, combined factorially with seven levels of mulch cover (0, 0.5, 1, 2, 4, 8 and 10 tha^{-1}) (Plate 3.7). As part of a planned rotation, maize, cowpea

and sorghum were grown at the Matopos site between 2004/05 and 2007/08 seasons and a new field was opened in each season (Table 3.2). A sole maize crop was grown at the Lucydale site during the 2004/05 to 2005/06 growing seasons. Crop yields, soil water content and soil physical and chemical properties were measured in the experiment. The experimental details and results are presented in Chapters 9a, 9b and 9c.



Plate 3.7. Maize growing in the basin tillage system and under 4 t ha^{-1} mulch cover at the Matopos clay soil site in March 2008 during the 2007/08 season

Table 3.2. Experimental fields used and crops grown in each field from 2004/05 to 2007/08 seasons at Matopos Research Station

Field number	Period under CA (seasons)	Season(s) field was used	Crop sequence
1	1	2007/08	Maize (M)
2	2	2006/07 and 2007/08	Maize – maize (MM)
3	3	2005/06, 2006/07 and 2007/08	Maize – cowpea – maize (MCM)
4	4	2004/05, 2005/06, 2006/07 and 2007/08	Maize – cowpea – sorghum - maize (MCSM)

3.6.2 Crop yield, soil water and infiltration measurements

Crop yield from each treatment was determined from a netplot consisting of five middle rows with a running length of 6 m. In the 2004/05 and 2005/06 seasons, soil water was measured using the gravimetric method. Soil samples were collected from on-farm and on-station experimental sites using equipment shown in Plate 3.8. During the 2006/07 and 2007/08 seasons, soil water measurements were taken using the microgopher capacitance probe (Plate 3.9). During April 2008, infiltration measurements were taken from selected tillage and mulch cover combinations at Matopos in all the four fields used in the experiment. A minidisk infiltrometer was used for measuring infiltration (Plate 3.10). The details of soil water and infiltration measurements and results are presented in Chapters 7, 8, 9a, 9b and 9c.

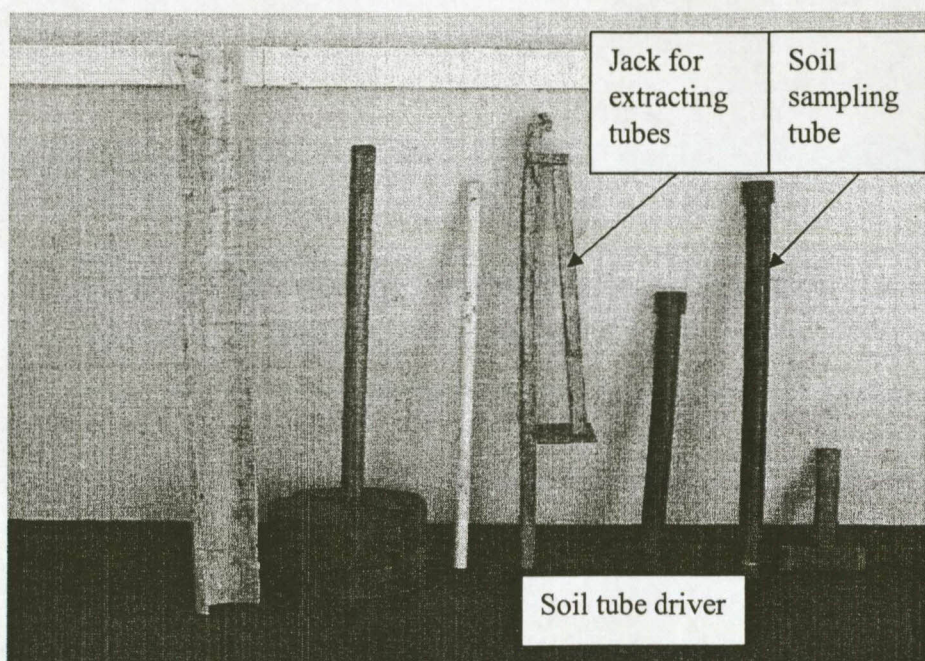


Plate 3.8. Soil sampling equipment used for collecting soil samples for gravimetric soil water determination in 2005/06 growing season

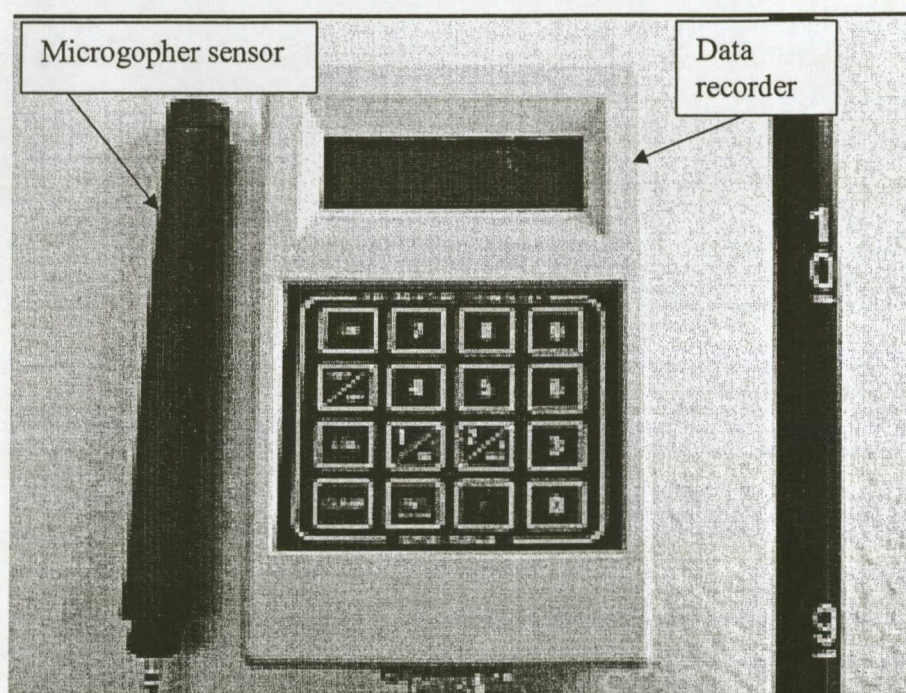


Plate 3.9. Capacitance probe used for soil water measurement during 2006/07 and 2007/08 seasons

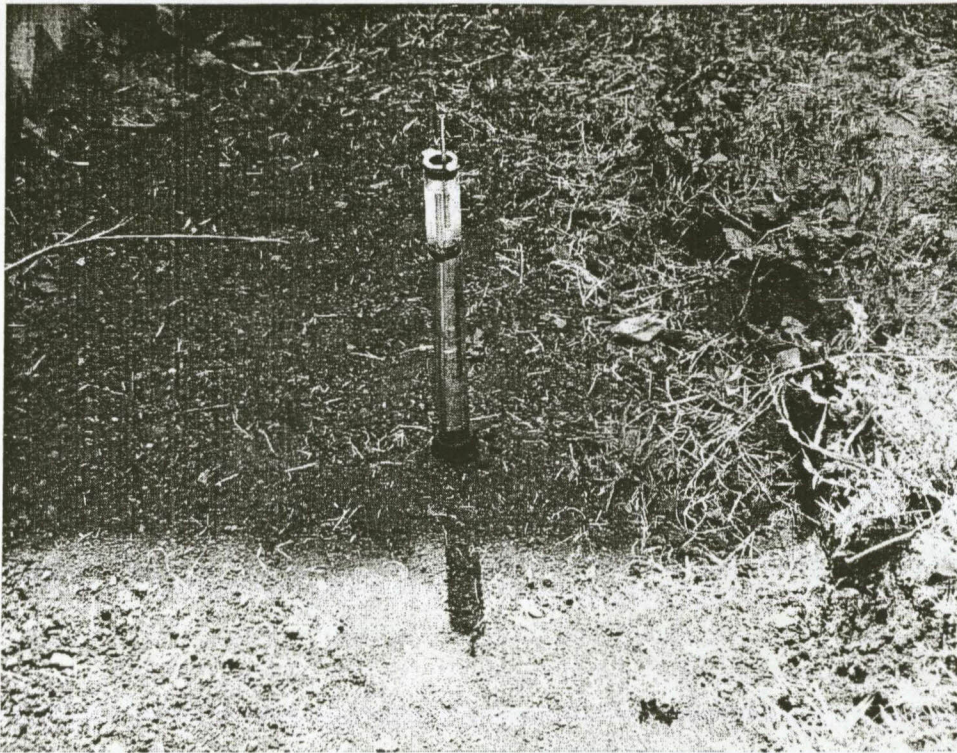


Plate 3.10. Minidisk infiltrometer used for measuring infiltration in fields exposed to conservation agriculture practices for one, two, three and four growing seasons at Matopos site in April 2008

3.7 Simulation modelling

On-farm crop and soil data showed a lot of variability across the farms used during the three seasons of experimentation. These data sets were therefore considered not suitable for calibrating APSIM. Crop and soil data collected from on-station experiments were used for evaluating the performance of APSIM model as there was less variability in the datasets. The APSIM model was tested for two soil types, clay and sand, to check how close the model could predict the observed soil and crop data. The light textured soil at Lucydale has properties similar to those found in granite-derived sandy soils of the smallholder farming areas in Gwanda and Insiza districts of southern Zimbabwe and was therefore used for the long term simulation in the present study. Daily rainfall, temperature and radiation data were collected from Matopos Research Station weather station which is located 3 km from Matopos experimental

site and up to 10 km from the Lucydale site. The climate record used for APSIM calibration stretched from 1 October 2004 to 30 June 2008. The details of the setting up of the APSIM model and results from the simulations are given in Chapter 10.

CHAPTER 4

Characterisation of Rainfall Pattern for Improved Crop Production

in Semi-Arid Cropping Systems of Southern Zimbabwe

4.1 Introduction

Total annual rainfall in semi-arid southern Zimbabwe is less than 500 mm (against national average of 657 mm) and exhibits spatial and temporal variation (Unganai, 1996; Phillips *et al.*, 1998). Total annual rainfall decreases from 800 mm in the north-east of Zimbabwe to less than 400 mm in the south (Unganai, 1996). Zimbabwe has a unimodal rainfall pattern falling between October and April (Unganai, 1996; Phillips *et al.*, 1998). The rainy season reaches the peak during January and February, and distribution during the season depends on the interplay between tropical and mid-latitude weather systems (Clay *et al.*, 2003). In semi-arid southern Zimbabwe the rains are poorly distributed during the growing season and often occur as high intensity convective storms (Rockström and Falkenmark, 2000). Typical coefficients of variation range between 20 and 40 % in semi-arid NRs IV and V of Zimbabwe increasing with decreasing seasonal rainfall averages (Oosterhout, 1996).

Smallholder agriculture in semi-arid southern Zimbabwe is heavily dependant on the seasonal characteristics of the rainfall. An analysis of the amount and distribution of rainfall in NR II, IV and V of Zimbabwe showed that the cropping season averages 96 days (Morse, 1996). In NR V the season starts early December and finishes in March (Morse, 1996). Analysis of rainfall data from northern Zimbabwe (Sebungwe) indicated that the length of the growing season increased with earlier onset of the rainy season (Chiduza, 1995). A strong relationship ($R^2 = 0.76$) between onset and

duration of rainfall has been reported in some parts of semi-arid southern Africa (Kanemasu *et al.* (1990).

In semi-arid southern Zimbabwe a false start of rain during the November and December period may be followed by a long dry spell and this can be fatal to crop establishment (Stern *et al.*, 1981; Dennett, 1987). Water-related problems in semi-arid smallholder agriculture are often complicated by occurrence of intra-seasonal dry spells during critical stages of crop growth (Rockström *et al.*, 2003; Oosterhout, 1996). Intra-seasonal dry spells are recurrent in southern Zimbabwe, often coinciding with anthesis stage of commonly grown cereals (maize, sorghum, pearl millet). Approximately 480 mm of rainfall, well distributed within the growing season, is sufficient for successful production of sorghum and maize crops (Unganai, 1990). Analysis of rainfall data provides important information for agricultural management in semi-arid cropping systems. The determination of start and end of summer rainfall season, and length of growing season, together with the frequency and duration of dry spells is useful to farmers in selecting suitable crop types and varieties, and timing of farming activities.

4.2 Objectives

This study was designed to determine

- (1) trends of total annual rainfall;
- (2) the start and end of growing season;
- (3) trend of wet days per growing season;
- (4) probability of dry spells during growing season and

(5) behaviour of first and second halves of the growing season in semi-arid southern Zimbabwe.

4.3 Materials and Methods

4.3.1 Data analyses

4.3.1.1 Test for homogeneity of total annual rainfall data

Rainfall data, based on the July to June calendar, were subjected to a test of homogeneity using the Run test (Freund, 1979; Dixon and Massey, 1983). A Run is defined as a sequence of like events or symbols that are preceded and followed by an event or symbol of a different type or by none at all (Freund, 1979). The Run test was conducted on total annual rainfall for each station based on the July to June calendar. The median of the total annual rainfall data was calculated at each station. The median was then subtracted from each total annual rainfall value in the data series. The number of times the data would make a run above (positive) or below (negative) the median was counted. This gave the persistence of positive and negative values from the annual rainfall data series. Significance tables were used based on the number of runs (denoted by 'u') and number of positive values (N_A) to determine thresholds for homogeneity.

4.3.1.2 Standardized precipitation index (SPI)

To assess the trends in drought throughout the periods under review at each station, standardized precipitation indices for each station were calculated using the following procedure outlined by Le Barbe *et al.* (2002):

$$SPI = (P - M) / S$$

Equation 4.1

where P is total annual rainfall for each year in the data series, M is mean rainfall for the data series and S is the standard deviation for the data series. The categories in Table 4.1 were adopted for classifying the data series according to wetness and dryness.

Table 4.1. Drought classification indices adapted from Hayes *et al.* (1999)

SPI value	Drought category
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and below	Extremely dry

4.3.1.3 Dry and wet days

Meteorologically a wet day definition of 'any day with more than 0.85 mm accumulated in 1 or 2 days' might suffice. However, for crop production purposes in a region experiencing daily pan evaporation of 5 - 8 mm (Woltering 2005) rainfall of 0.85 mm has very limited influence on crop growth. Stern *et al.* (2003) suggest that for other purposes a threshold of 4.95 mm can be used to define a wet day. For the purposes of our study in semi-arid southern Zimbabwe the following definitions were used in the analyses of dry and wet days;

- Dry day: Any day that accumulates less than 5 mm of rain in 1 day
- Wet day: Any day that accumulates 5 mm or more in 1 day

4.3.1.4 Start and end of growing season

The start and end of the growing season were defined as;

- Start: the first day after 1 October when the rainfall accumulated over 1 or 2 days is at least 20 mm (Stern *et al.*, 2003)

- End: the last day before 30 June that accumulates 10 mm or more rainfall in 1 day

The cut off point for end of season catered for late maturing or late planted crops. After 1 June temperature normally drops quite significantly and crop growth rate is slowed down. Given the above definitions Instat Statistical programme (Version 3.33) (Stern *et al.*, 2003) was used to analyse the rainfall data for start and end of season, and length of the growing season. The *F*- and *t*-tests, to confirm significance of change in total annual rainfall, number of wet days per growing season, start and end of growing season, were conducted using Genstat Discovery Edition 3 (www.vsni.co.uk). Regression analysis was conducted to determine the relationship between start and length of growing season.

4.3.1.5 Dry spell analysis

Daily rainfall data for each station was fitted to the simple Markov chain model as outlined by Stern *et al.* (1982; 2003). The Markov chain model was run so that it will give the probability of getting 14 and 21 day dry spells using the July to June calendar. The analyses were performed using Instat Statistical Programme (Version 3.33, <http://www.reading.ac.uk/ssc/software/instat/climatic.pdf>) (Stern *et al.*, 2003).

4.3.1.6 Cumulative distribution functions for first and second halves of rainy season

In-season rainfall patterns normally vary between the first and second halves of the growing season. To assess the rainfall pattern in the two halves of the growing season, the rainy period was divided into two, first half covering the October to December period and second half starting in January and ending in March. Three monthly

rainfall totals were used to determine the below-normal, near-normal and above normal rainfall ranges during each half of the growing season.

4.4 Results and Discussion

4.4.1 Test for homogeneity of total annual rainfall data

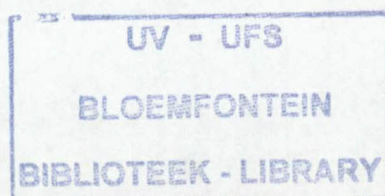
The Run test showed a fairly equal persistence of counts below and above the median rainfall amount for each station (Table 4.2). At Mbalabala and Beitbridge there were marginally more total annual rainfall values greater than the long term median rainfall for the data series reviewed. At Bulawayo, Matopos and Filabusi there was an equal number of total annual rainfall values greater and less than the long term median rainfall. The distribution of the total annual rainfall values around the median rainfall values suggests that data for each station was drawn from a homogenous sample.

Table 4.2. Homogeneity test for annual total rainfall for the five meteorological stations in southern Zimbabwe

Station	Median (mm)	Number of runs	Total count	Positive counts (N _A)	Negative counts (N _B)
Bulawayo	561	28	71	34	38
Matopos	537	39	69	35	34
Mbalabala	617	42	64	21	21
Filabusi	538	37	74	36	36
Beitbridge	362	20	50	26	24

4.4.2 Total annual rainfall

The gradient of rainfall from Bulawayo (NR IV) southwards towards Beitbridge (NR V) can clearly be seen on the mean and median values as well as the long term graph of annual values (Figs. 4.1 and 4.2). However, variability is also seen at each station with extremes of over 1 200 mm at Bulawayo and lowest of less than 100 mm at Beitbridge with an extremely high coefficient of variation of 44 %. The total annual rainfall variations for the Bulawayo, Matopos and Mbalabala stations in semi-arid



southern Zimbabwe are summarized in Figure 4.1. There was no significant ($P = 0.996$) change in total annual rainfall at Bulawayo over the 71 year period. The lowest annual rainfall recorded at Bulawayo was 199 mm in 1947, and the highest rainfall was 1 259 mm received in 1978. The long term average annual rainfall for Bulawayo based on these data was 584 mm with standard deviation of 206 mm and coefficient of variation of 35 % (Table 4.3). At Matopos total annual rainfall decreased ($P = 0.506$) slightly between 1960 and 2000, and the lowest annual rainfall (263 mm) was recorded in 1991. The 69 year average rainfall for Matopos was 573 mm with standard deviation 203 mm and coefficient of variation of 35 % (Table 4.3). At both Bulawayo and Matopos the driest periods were 1960-1972 and 1980 to early 1990 (Fig. 4.1).

Table 4.3. Characteristics of the total annual rainfall (based on July-June calendar) recorded at five meteorological stations in semi-arid southern Zimbabwe

Station	Mean (mm)	Median (mm)	Standard deviation (mm)	Coefficient of Variation (%)	NR
Bulawayo	584	561	206	35	IV
Matopos	573	537	203	35	IV
Mbalabala	626	617	213	34	IV
Filabusi	546	538	185	34	IV
Beitbridge	376	362	166	44	V

Total annual rainfall decreased ($P > 0.05$) in Filabusi and Mbalabala stations between 1980 and 2000 with 546 and 626 mm being average rainfall recorded for the two stations (Table 4.3 and, Figs. 4.1 and 4.2). At Mbalabala the lowest rainfall was 195 mm recorded in 1991. The lowest annual rainfall was 250 mm recorded in 1945 at Filabusi. The 1959 to 1973 was the driest period at Mbalabala while 1980 to 1990 was the driest decade at Filabusi since record keeping began in 1921. Beitbridge recorded the lowest rainfall amount of 83 mm in 1982. The highest rainfall at Beitbridge was

1177 mm recorded during the 1999-2000 rainy season and this coincided with the period when cyclone Eline was experienced in the southern parts of Zimbabwe. The driest period at Beitbridge was between 1960 and 1970 (Fig. 4.2).

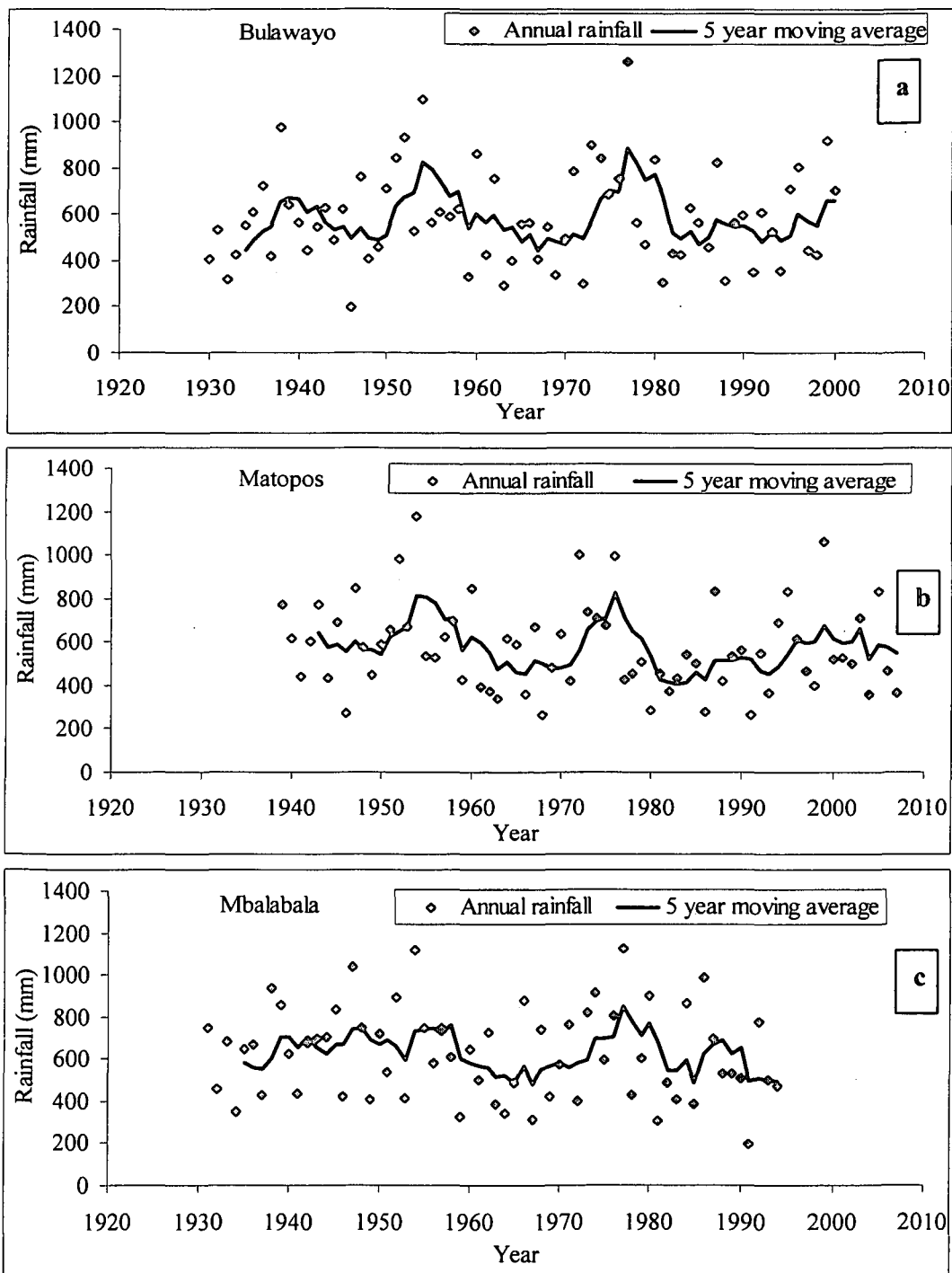


Figure 4.1. Total annual rainfall (July to next June) for Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations of semi-arid southern Zimbabwe

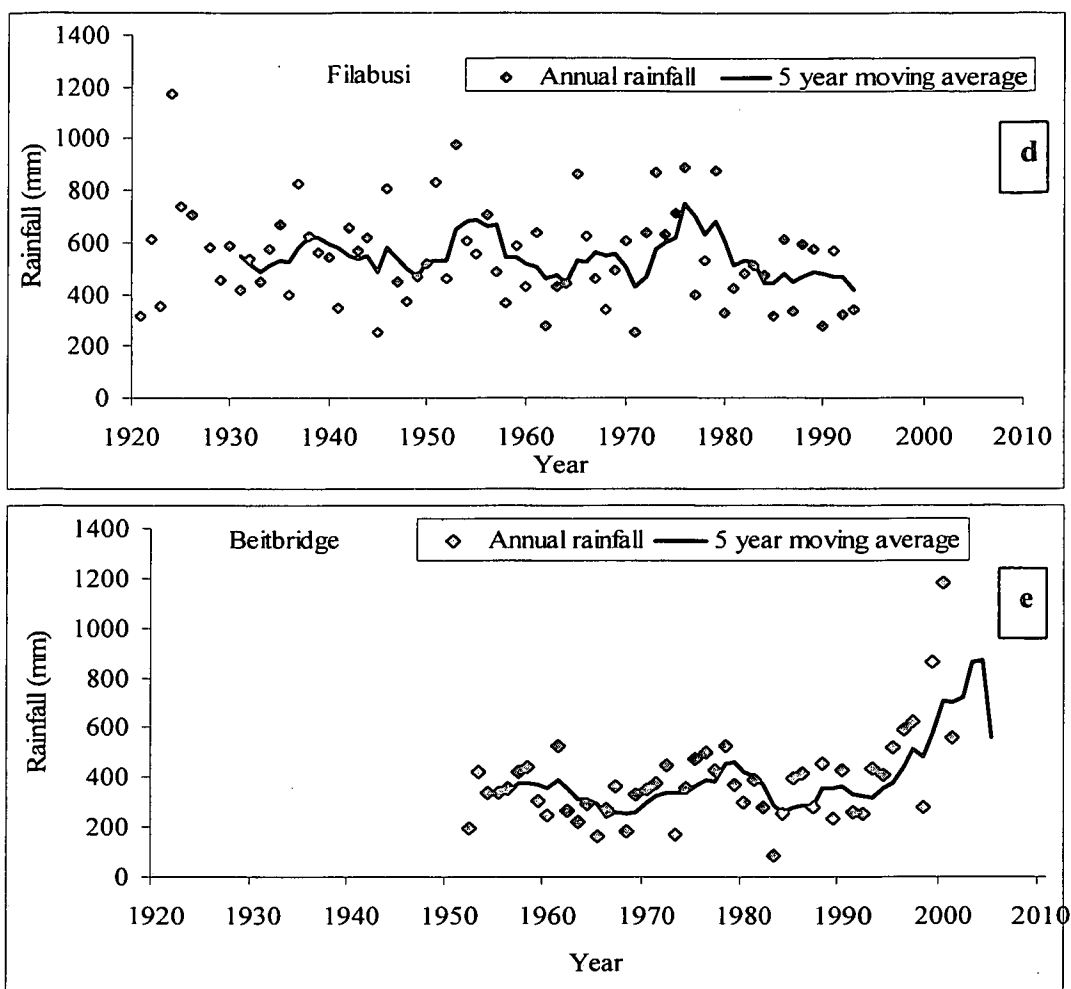


Figure 4.2. Total annual rainfall for Filabusi (d) and Beitbridge (e) meteorological stations of semi-arid southern Zimbabwe

The slight decline in total annual rainfall has also been observed in studies conducted by Unganai (1996) using Global Climate Models (GCM). The study by Unganai (1996) showed a 10 % decline in total rainfall over Zimbabwe between 1900 and 1993. From the same study by Unganai (1996) from the late 1950s to about 1972 and 1980 to 1993 were the driest periods in Zimbabwe. This compares well with the current analysis as three of the stations had 1960 to early 1970s as the driest period on record, whereas two stations had 1980 to early 1990s as the driest decade. Globally Trenberth *et al.* (2007) also reported a similar trend of declining annual rainfall and this has been attributed to a number of reasons including a decrease in the number of

wet days (Christensen *et al.*, 2007). Other possible explanations for this decreasing trend in rainfall include the effect of land use changes on moisture cycling, and the increasing frequency and severity of El Niño events (Trenberth *et al.*, 2007).

The coefficient of variation for total annual rainfall increased with decreasing mean annual rainfall (Table 4.3). This suggests that the drier areas experience higher rainfall variability than wetter areas in southern Zimbabwe. The coefficient of variation range of 34 to 44 % is higher than 28 to 36 % reported by a previous study by Oosterhout (1996) in Zimbabwe's NRs IV and V. Despite the lack of significant changes in total annual rainfall, farmers in semi-arid southern Zimbabwe still experience crop yield reductions due to soil water stress. This seems to suggest that in-season rainfall distribution plays a more significant role in semi-arid crop production than total annual rainfall. Clay *et al.* (2003) reported that dry spells that occur at reproductive stages of crops reduce yields substantially even if total annual rainfall is at or near normal. Unganai (1990) reported that approximately 480 mm of rainfall, well distributed within the growing season was sufficient for successful production of sorghum and maize crops. Tadross *et al.* (2007) further reported that there has been a shift towards more sporadic rainfall events during the rainy seasons.

Beitbridge represents the southern part of Gwanda district where the on-farm experiments were conducted during 2005/06, 2006/07 and 2007/08 growing seasons. Seasonal rainfall distribution was erratic during two (2006/07 and 2007/08) of the three seasons of experimentation and dry spells were experienced in January and February in each of the seasons (Chapters 7 and 8). In Insiza district, represented by Filabusi station, erratic rainfall distribution and dry spells during the 2006/07 and

2007/08 seasons were also experienced. In both districts 60 to 75 % of the farmers hosting research trials experienced total crop failure on the research plots as well as their other fields. This is consistent with simulation modelling results (Chapter 10) which showed that total crop failure can be experienced in both the conventional and planting basin systems regardless of the amount of nitrogen fertilizer used. During the four years of experimentation at Matopos site, represented by Matopos meteorological station, three (2004/05, 2006/07 and 2007/08) out of the four growing seasons experienced dry spells in January and February. However, no total crop failure was experienced at Matopos site probably due to the fact that the clay soil at the site managed to supply soil water until the maize crop matured (Chapter 9a and 9b).

4.4.3 Standardized precipitation index

The year 1977 was the wettest at Bulawayo while the most severe drought was recorded in 1946 (Fig. 4.3). At Matopos 1954 was the wettest year and 1946, 1968 and 1991 had the most severe drought at Matopos (Fig. 4.3). The wettest year at Mbalabala was 1977 and the most severe drought at Mbalabala was recorded in 1991. The wettest year at Filabusi was 1924 and driest year was 1946. No year fell into extremely or very wet at Beitbridge. Only four years namely 1995, 1996, 1999 and 2000 were moderately wet. The most severe drought was recorded in 1998 at Beitbridge (Fig. 4.4). The relatively wet period stretching between 1995 and 2000 coincide with the El Niño/La Nina events of 1997 to 1999 (Rosenzweig, 2001). The 1991/92 drought was one of the worst throughout southern Africa (Rosenzweig, 2001).

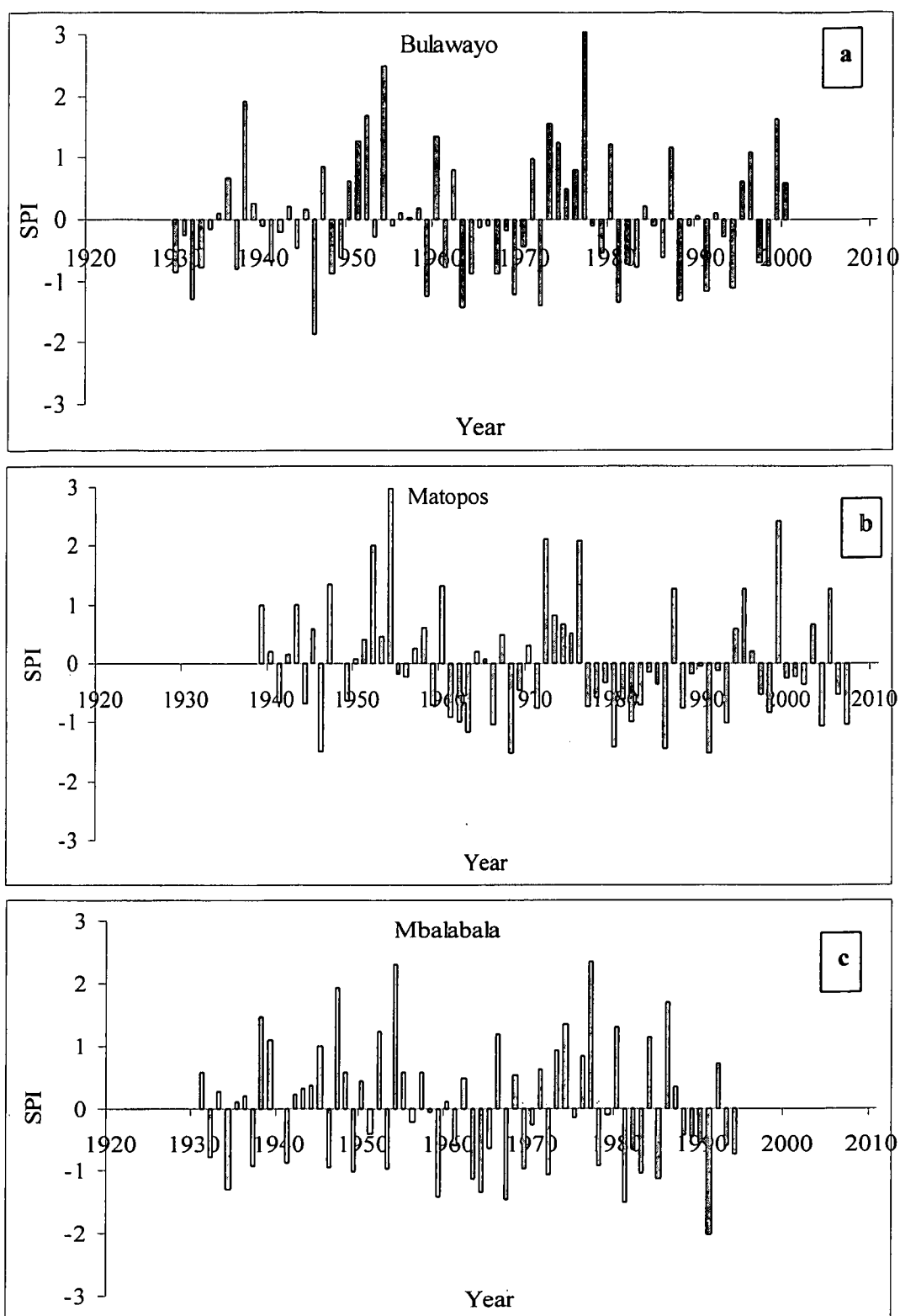


Figure 4.3. Standardized precipitation indices derived from total annual rainfall data for Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations

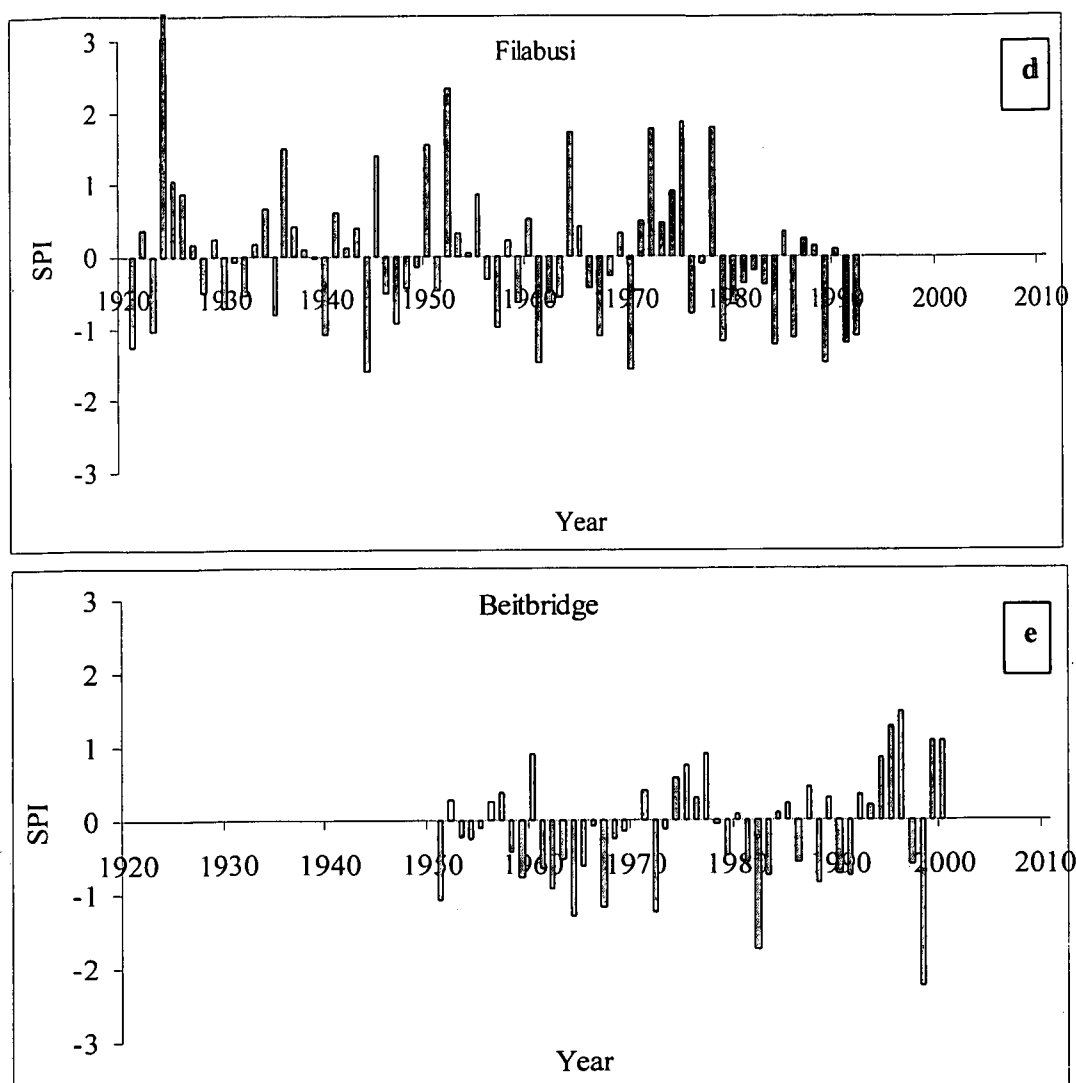


Figure 4.4. Standardized precipitation indices derived from total annual rainfall data for Filabusi (d) and Beitbridge (e) meteorological stations

4.4.4 Wet days per growing season

The changes in number of wet days per growing season based on daily rainfall data derived from Bulawayo and Matopos meteorological stations in southern Zimbabwe are shown in Figure 4.5. There was a negligible difference in the number of wet days per season as one moves from Bulawayo to Filabusi station through Matopos and Mbalabala (Figs. 4.5 and 4.6). All four stations are located in NR IV. Our findings are inconsistent with results reported by Hudson and Jones (2002) who stated that there has been a general decrease in the number of wet days per year in southern Africa.

Hudson and Jones (2002) defined a wet day as a day receiving more than 0.2 mm of rain whereas in our study we defined a day with 5 mm or more rainfall as wet. In addition our study focussed on number of wet days per growing season and not the whole year. As expected Beitbridge which lies in NR V, had the least ($P = 0.01$) number of wet days per growing season.

The average number of wet days per growing season recorded at Bulawayo was 21, Matopos was 22, Mbalabala was 24, Filabusi was 22 and Beitbridge was 12. At Bulawayo station the lowest number of wet days per season recorded was four in 1946/47 and 1981/82. Forty-two wet days were recorded in 1977/78 was the highest number observed at Bulawayo. Matopos recorded seven and 45 wet days in 1990/91 and 1954/55 seasons. Mbalabala recorded eight and 48 wet days in 1983/84 and 1954/55 seasons. Filabusi station recorded eight and 46 wet days per growing season in 1946/47 and 1954/55 seasons. Three and 31 wet days per growing season were recorded at Beitbridge station in 1964/65 and 1999/00 seasons. Using the October-September hydrological year and definitions of a wet day having more than 10, 20 and 30 mm rainfall, Love *et al.* (2008) assessed the trend in number of wet days per year in southern Zimbabwe. Findings from their study revealed a decline in number of days with more than 10, 20 and 30 mm of rainfall per year in southern Zimbabwe. However, this is not apparent from the current analysis with a wet day defined as above 5 mm.

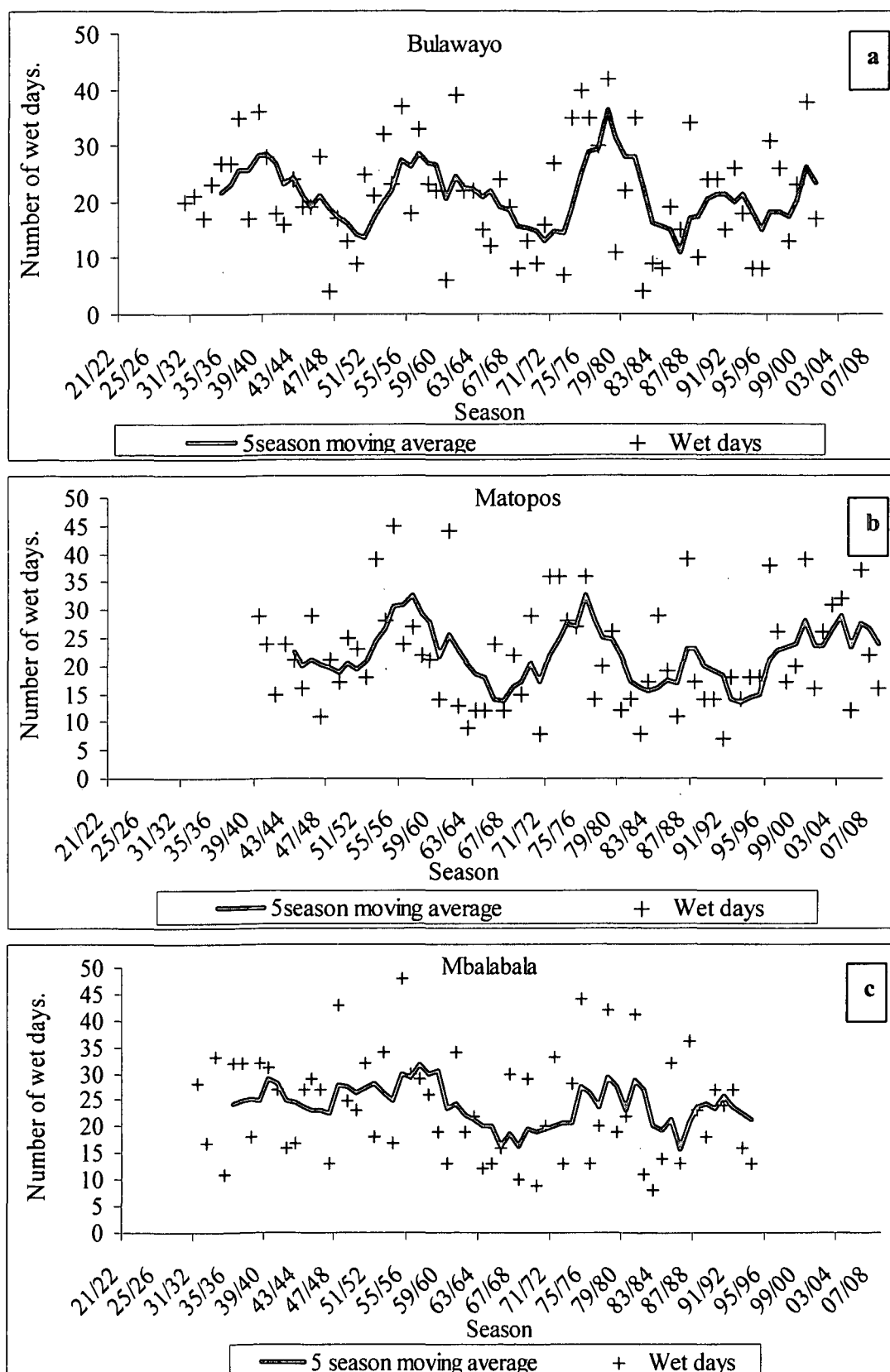


Figure 4.5. Number of wet days per season based on daily rainfall data obtained from Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations

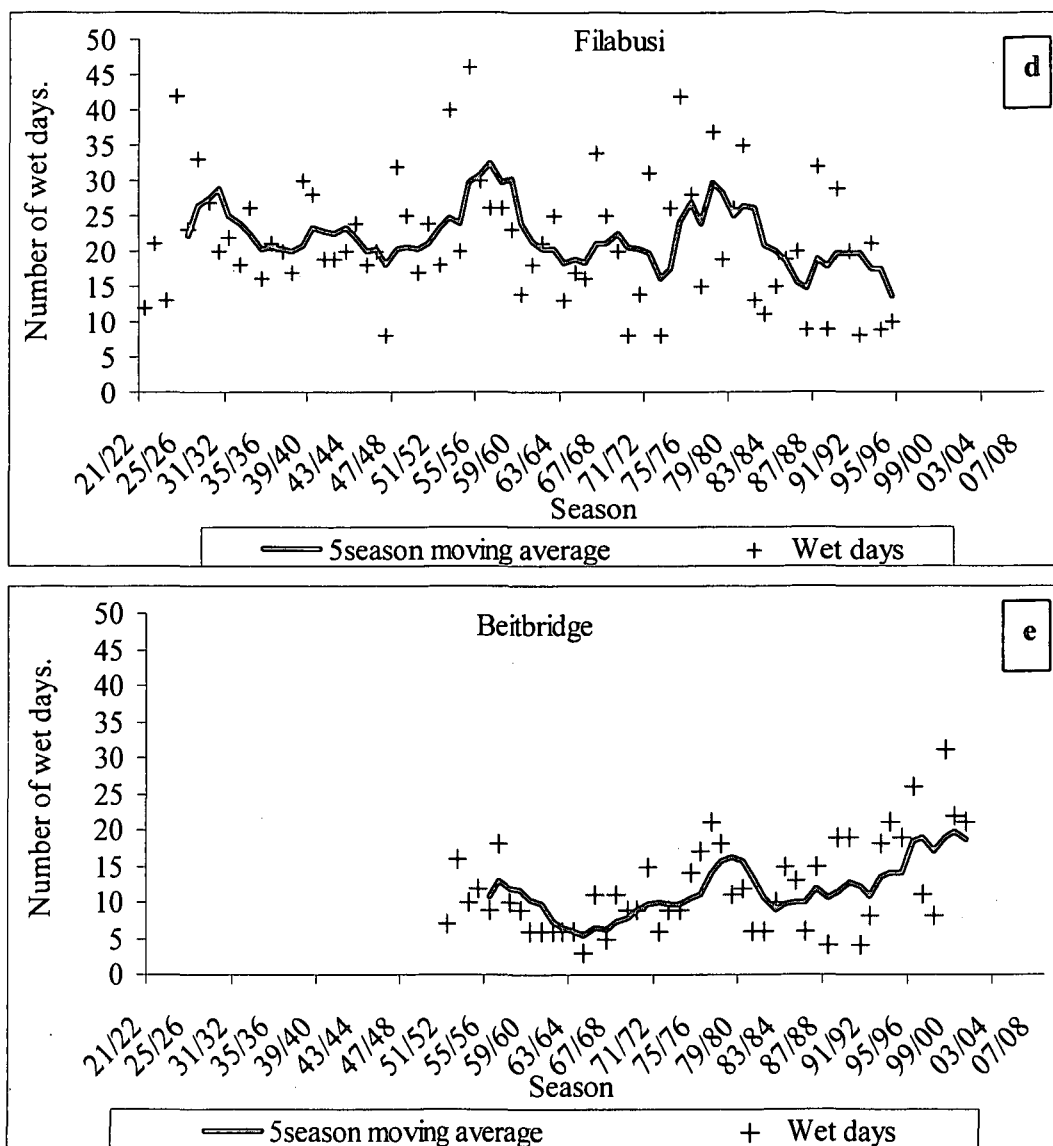


Figure 4.6. Number of wet days per season based on daily rainfall data obtained from Filabusi (d) and Beitbridge (e) meteorological stations

At Bulawayo and Matopos the trend of wet days per season follows a similar pattern to that of total annual rainfall. The driest decade (1980-1990) had the lowest number of wet days per season. At Bulawayo and Matopos the return period of seasons with high rainfall is 18 to 22 years. The 1961 to 1978 period had the least number of wet days per season at Mbalabala (Fig. 4.5) which coincides with the period of lowest annual rainfall. Return period for high number of wet days per season was 21-26 years at Mbalabala and Filabusi. Further south, Beitbridge appears to receive

relatively wet growing seasons after more than 20 years although the record is only 50 years long.

4.4.5 Start and end of growing season

There has been no significant ($P > 0.05$) change in the start of growing seasons at each station across the Bulawayo to Beitbridge transect (Table 4.4, Figs. 4.7 and 4.8). The variability of start and end of the growing season is quite similar at all stations along the Bulawayo to Beitbridge transect. The growing season generally starts earlier at Filabusi and ends earlier at Beitbridge (Table 4.4). At Bulawayo the growing season starts on 8 December and ends on 4 April (Table 4.5) giving an average season length of 117 days. The earliest start of season was 26 October (117 days from 1 July) and this occurred in 1988/89. The most delayed start of growing season was recorded in 1981/82 when the season started as late as 3 March (day 246). At Matopos the growing season long term start on 2 December and ends on 29 March. The earliest start of growing season was recorded on 21 October (day 112) in 1978/79 and 2001/02. The most delayed start of growing season at Matopos occurred on 23 February (day 237) in 1981/82. At Mbalabala growing season starts on 3 December and ends on 1 April. The earliest start of growing season was on 30 October (day 122) and recorded in 1980/81 and 1985/86. The most delayed start of season occurred on day 261 (18 March) in 1976/77. Growing season starting as late as 18 March can be attributed to the criteria of start of season of 20 mm of rain in one or two days used in our study. At Filabusi the growing season starts on 28 November and ends on 3 April station. The earliest start of season was observed in 1931/32 and occurred on day 102 (10 October). The most delayed start of season was in 1988/89 and occurred on day 229 (14 February). At Beitbridge which was the driest station studied, the season

starts on 7 December. The earliest start of season was recorded on day 102 (10 October) in 1931/32 and the most delayed start occurred in 1988/89 on 14 February (day 229).

Table 4.4. Median dates for the start and end of the growing season based on daily rainfall data obtained from five meteorological stations in southern Zimbabwe

Station	Median start date	Standard deviation (days)	Median end date	Standard deviation (days)
Bulawayo	8 December	31	4 April	32
Matopos	2 December	30	29 March	31
Mbalabala	3 December	26	1 April	27
Filabusi	28 November	26	3 April	30
Beitbridge	7 December	31	25 March	29

The most abrupt end of season at Bulawayo was recorded in 1964/65 when the season ended on 15 January (day 200). At Matopos the earliest end of growing season was recorded on 13 December (day 166) in 1979/80. At Mbalabala the earliest end of season was on 21 January (day 206) in 1932/33. The most abrupt end of growing season at Filabusi occurred on 20 January (day 205) in 1932/33. The end of 1958/59 growing season was the most delayed and occurred on 13 June (day 349) at Filabusi. At Beitbridge the season ends on 25 March. The most abrupt end of season at Beitbridge was recorded on 20 January. The most delayed end of season was in 1958/59 and occurred on 13 June. The abrupt end of the growing seasons observed in the long term analysis agrees with observations made during the three to four years (Chapters 7, 8, 9a and 9b). The 2007/08 growing season ended on 24 January 2008 in all semi-arid districts of southern Zimbabwe.

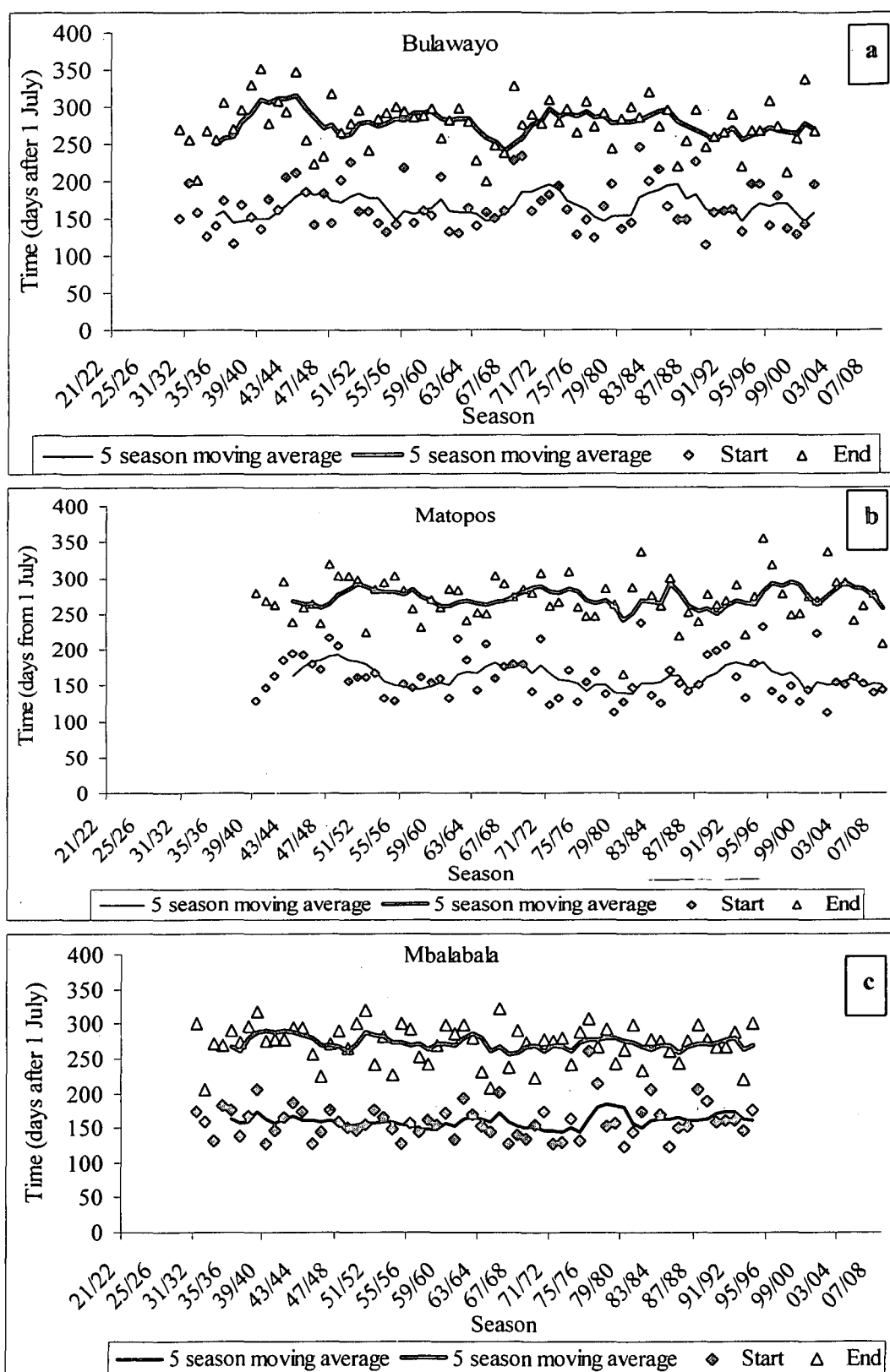


Figure 4.7. Start and end of growing seasons derived from daily rainfall data for Bulawayo (a), Matopos (b) and Mbalabala (c) Meteorological stations

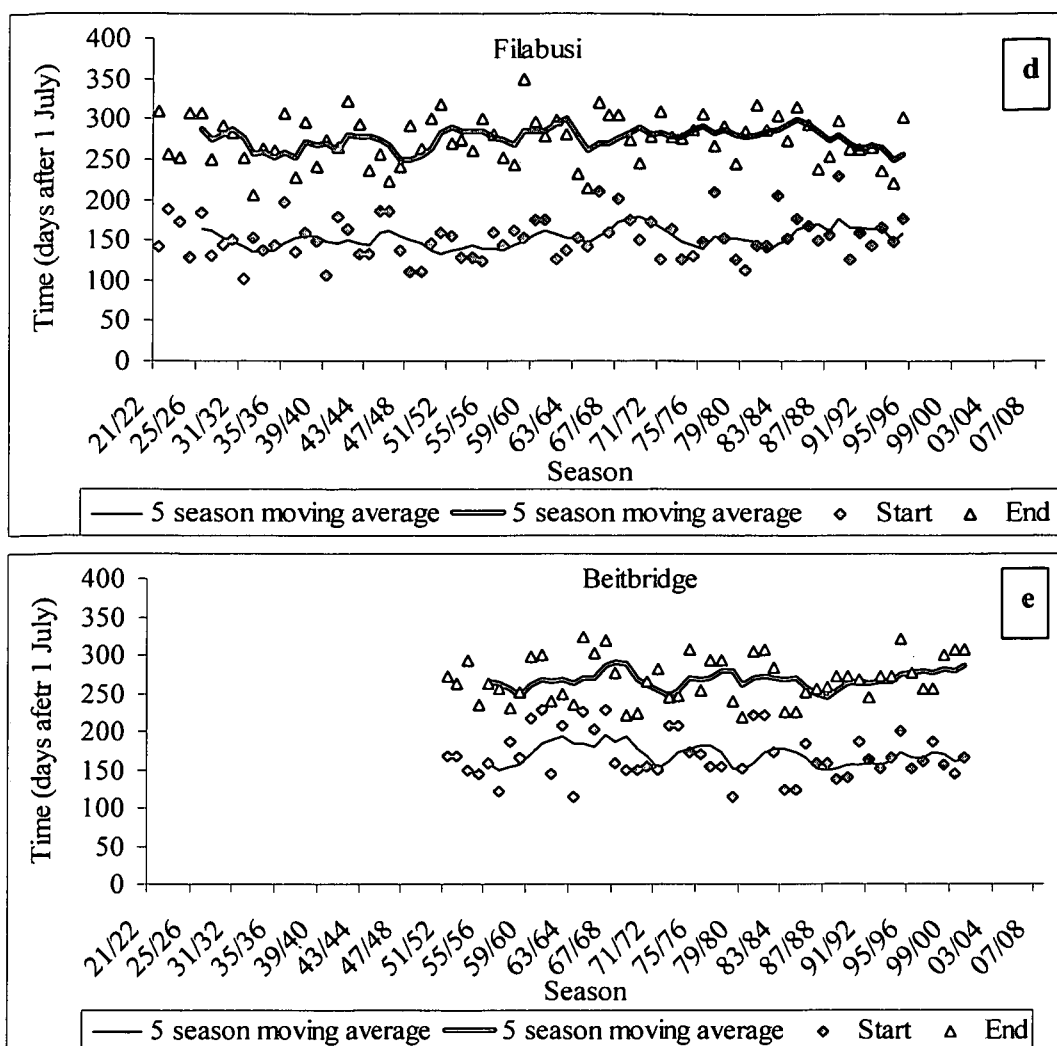


Figure 4.8. Start and end of growing seasons derived from daily rainfall data for Filabusi (d) and Beitbridge (e) meteorological stations

Aviad *et al.* (2004) from the Mediterranean region reported that as aridity increases the rainy season normally begins late and ends early, and subsequently the length of growing season is short. In our study smallholder farmers in Beitbridge face the prospects of a shorter growing season compared to those in NR IV as it only began on 7 December and ended on 25 March giving a length of only 108 days. This is further complicated by the fact that start of growing season is also more variable in Beitbridge than its end (Table 4.5). Farming practices that allow timely preparation of the land and planting are more critical in the Beitbridge area so that farmers can make effective use of rainfall received during the November to December period.

The lack of significant long term changes suggests that the characteristics of the growing season are influenced by other factors in addition to total rainfall and date of start of the rains. In Zimbabwe, Oosterhout (1996) reported that years that had the highest rainfall did not correspond with years having the highest crop yields. Distribution and reliability of rainfall during the growing season has a stronger influence on the characteristics of the growing period than total rainfall (Twomlow *et al.*, 2006b). High spatial and temporal rainfall variability during the season increases the risk of intra seasonal dry spells and droughts in semi-arid areas (Rockström and Falkenmark, 2000). Long term simulation results (Chapter 10) indicated that there is more than a 20 % chance of getting no yield in the conventional and CA systems under semi-arid conditions of southern Zimbabwe. Therefore other indices to be able to represent this distribution and variability need to be developed.

4.4.6 Length of growing season

The length of growing season decreased as one moves from Bulawayo to Beitbridge through Matopos, Mbalabala and Filabusi (Figs. 4.9 and 4.10). For the period reviewed at each station, the growing season averaged 111d at Bulawayo, 110d at Matopos, 112d at Mbalabala, 122d at Filabusi and 100 days at Beitbridge. The longest growing season recorded across the five stations was 224 days recorded at Matopos in 2001/2002 which is more than double the average length. The shortest growing season observed across the Bulawayo to Beitbridge transect was 38 days recorded at Filabusi and Beitbridge. The longest growing season at Bulawayo had 215 days and was recorded in 1939/40. The 1981/82 season was the shortest growing season with only 41 days which coincided with the lowest number of wet days (4). At Matopos the shortest growing season had 39 days recorded in 1979/80. In 1954/55 Mbalabala

recorded the longest season which had 173 days which was also the season with the highest number (48) of wet days. The shortest growing season at the same station was 46 days recorded in 1976/77. Filabusi recorded the longest growing season of 197 days in 1958/59 while the shortest season was 38 days recorded in 1946/47 which was the year with annual rainfall of 250 mm. At Beitbridge the longest growing season was 162 days recorded in 1999/00 which also recorded the highest number of wet days (31) and the highest annual rainfall (1177 mm) due to the cyclone Eline pushing in over the African landmass and causing severe flooding. The shortest season of 38 days was recorded in 1972/73 and 1973/74.

Results from our study showed an average length of the growing season of 111 days across the 5 stations. The 111 days length of growing season is much higher than 96 days reported by Morse (1996) for Zimbabwe's NRs II, IV and V. The differences in length of growing season could be ascribed to differences in the criteria used in defining the start and end of growing season. Tadross *et al.* (2007) reported that a growing season of 90-120 days can be experienced in southern African countries such as Malawi and Zambia. The above analysis confirms that there is no general rule of thumb that the season length is related to the amount of rainfall received but can have a relationship with the number of wet days or effective rainfall events. So if this southern part of Zimbabwe has an average season length of only 111 days, agronomists need to use this information in selecting suitable cultivars for smallholder farmers. The ultra short cultivars could be an option and this will help farmers to be able to plant early and produce a crop with less exposure to dry spells.

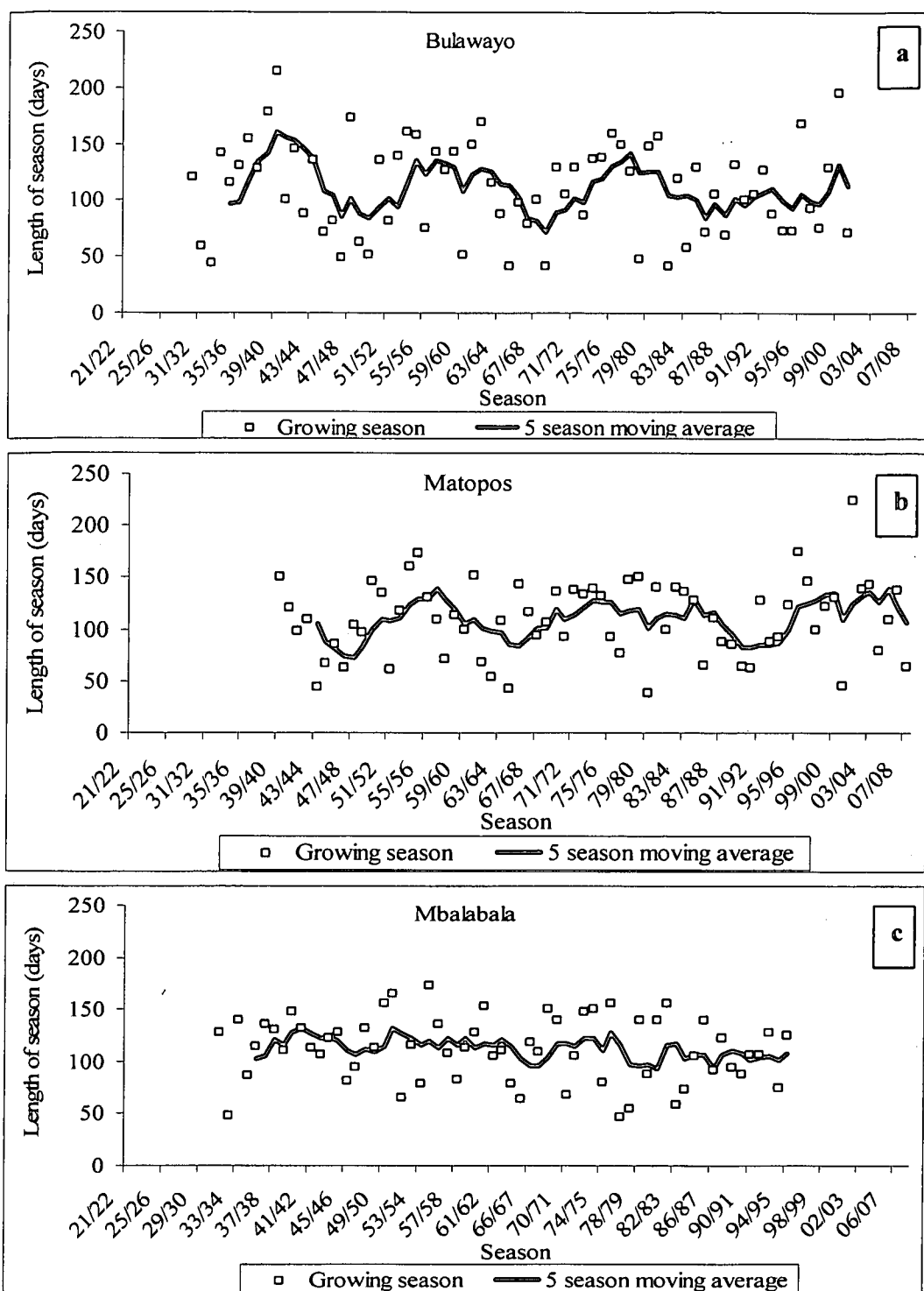


Figure 4.9. Length of the growing season based on daily rainfall data obtained from Bulawayo (a), Matopos (b) and Mbalabala (c) meteorological stations

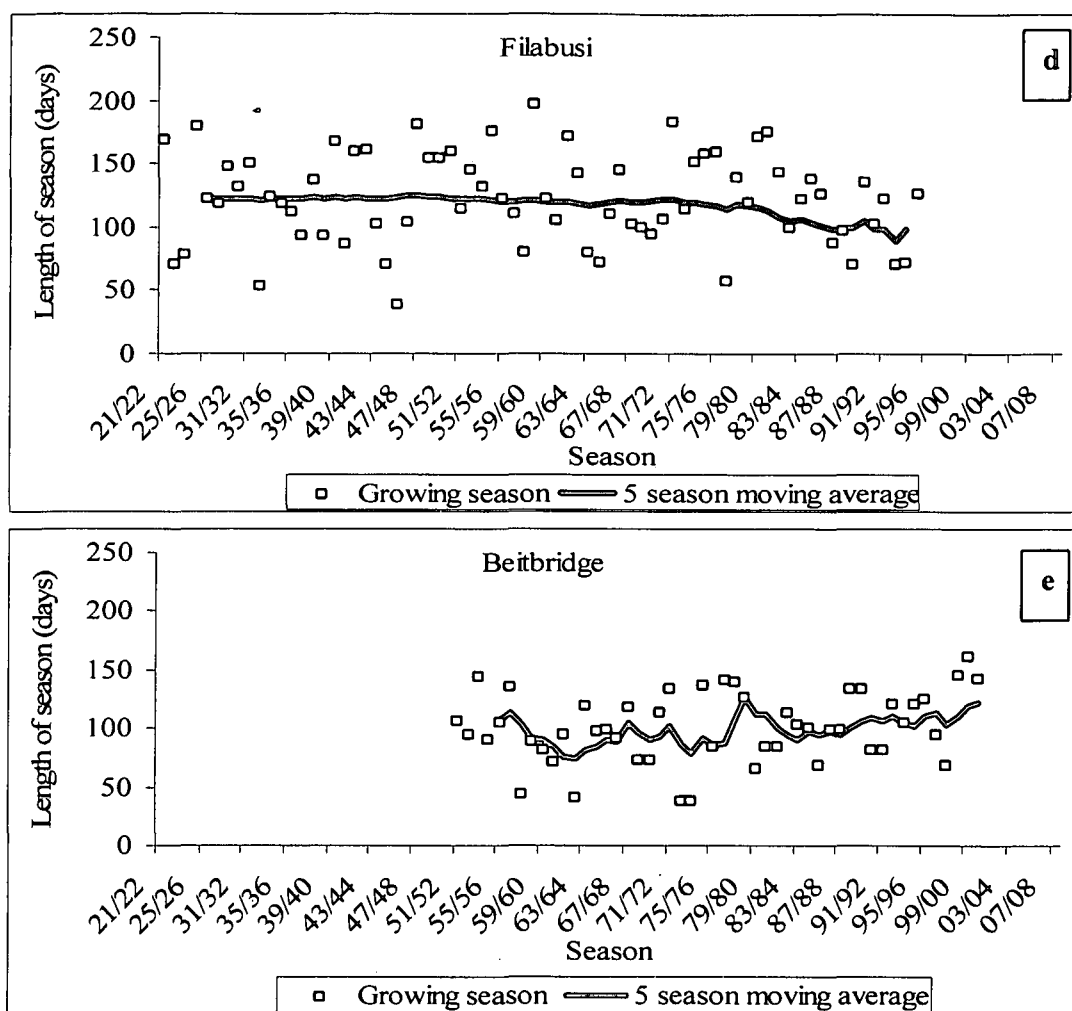


Figure 4.10. Length of the growing season based on daily rainfall data obtained from Filabusi (d) and Beitbridge (e) meteorological stations

Plotting length against start of growing season showed a negative inverse relationship for all five stations (Figs. 4.11, 4.12 and 4.13). Therefore a delay to the start of growing season results in a shorter season as it is often related with the end of season. Based on the R^2 -values and gradients of the slopes, the inverse relationship between length and start of season was strongest in the wetter part at Bulawayo (NR IV) and weakest at Beitbridge (NR V) being the driest part of the catchment. The strength of the relationship decreases as one move from Bulawayo to Beitbridge through Matopos, Mbalabala and Filabusi stations. The length of the growing season at Bulawayo is more influenced by the time when the growing season starts compared to

other stations. The time when growing season starts has the least influence on the subsequent length of growing season at Beitbridge compared to stations in NR IV. At Filabusi, which lies between Mbalabala and Beitbridge, the relationship between start and length of season is stronger than at Matopos and Mbalabala stations. A stronger relationship ($R^2 = 0.76$) between the start and length of the season was reported in Botswana and other parts of southern Africa (Kanemasu, 1990) while the highest R^2 in our analysis was 0.41 at Bulawayo (Fig. 4.13). Differences in the criteria for start and end of the season can probably explain the difference between values obtained in our analysis and results from Kanemasu (1990).

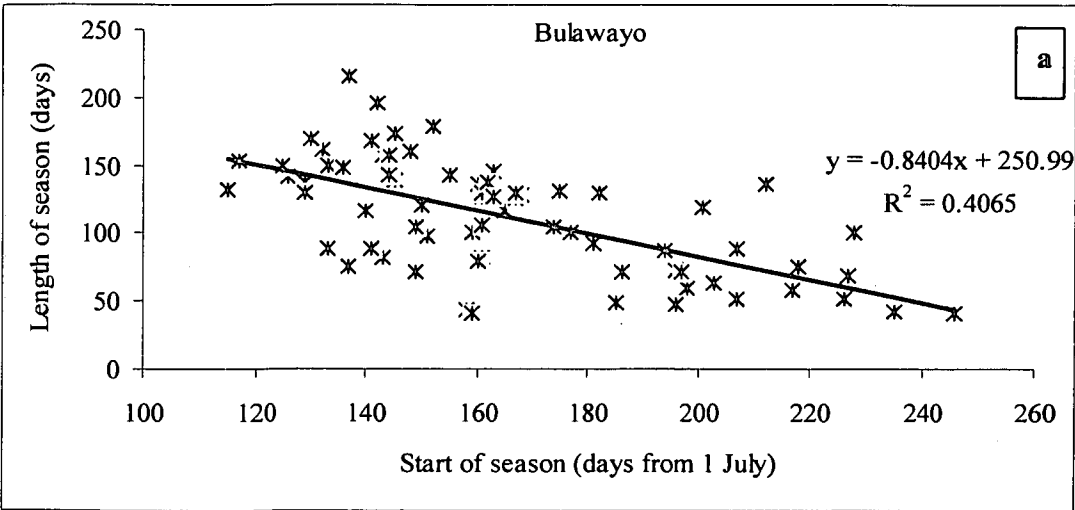


Figure 4.11. Relationship between length and start of growing season at Bulawayo (a) meteorological station in southern Zimbabwe

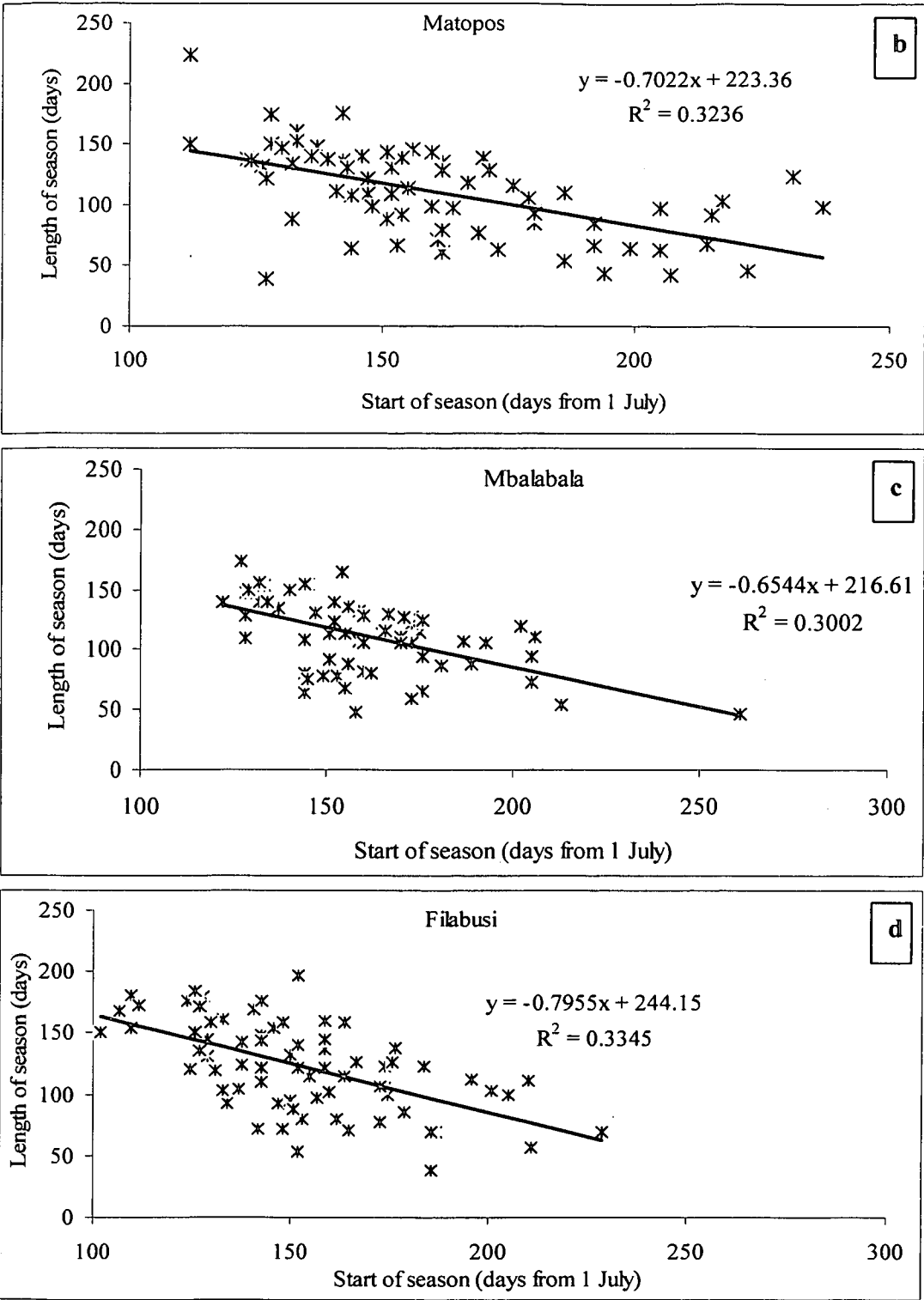


Figure 4.12. Relationship between length and start of growing season at Matopos (b), Mbalabala (c) and Filabusi (d) meteorological stations in southern Zimbabwe

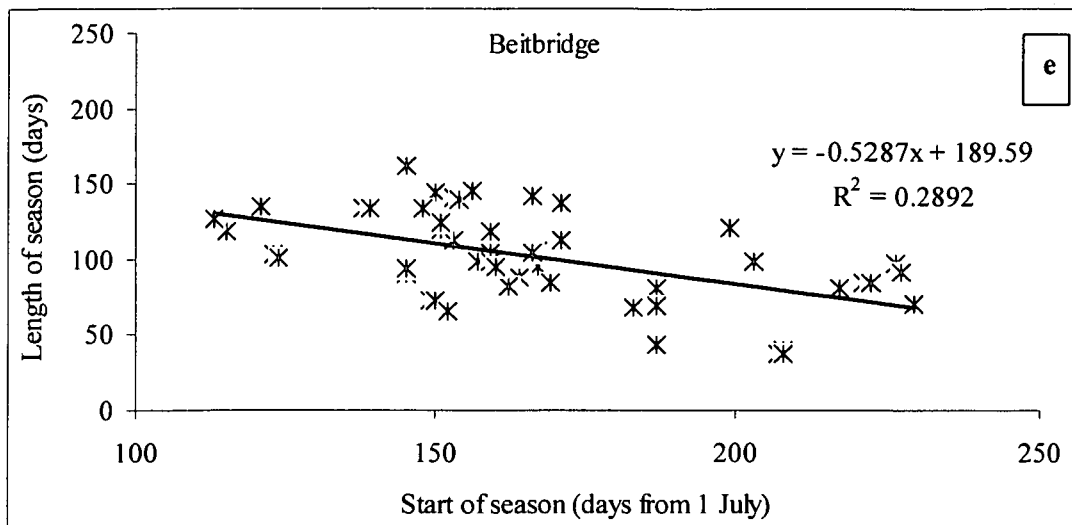


Figure 4.13. Relationship between length and start of growing season at Beitbridge (e) meteorological station in southern Zimbabwe

4.4.7 Dry spells

The peak rainfall period during the growing season occurs between December and February in southern Zimbabwe. The likelihood of getting 14 and 21 day dry spells during any time of the year is given in Figure 4.14 and Figure 4.15. Based on the data set reviewed, Filabusi has the highest chance of getting 14 and 21 day dry spells compared to the other four stations. Mbalabala has the least chance of getting a 21 day dry spell during the peak rainfall period from 120 to 240 days after 1 July. The probability of getting a 14 or 21 day dry spell decreases as one moves from Bulawayo to Mbalabala through Matopos. There is a 27 to 40 % chance of experiencing a 21 day dry spell at Bulawayo between 10 November (day 133) and 8 February (day 223). During the same period there is a 66 to 79 % chance of getting a 14 day dry spell at Bulawayo. At Matopos there is a 18 to 33 % chance of a 14 day dry spell occurring between 10 November and 8 February. During the same period 21 day dry spells have a 3 to 7 % chance of occurring at Matopos.

The probability of getting a 14 day dry spell at Mbalabala between 10 November and 8 February is 14 to 27 %. There is a 2 to 5 % chance of getting 21 continuous dry days during the same period. Fourteen day dry spells are a common feature at Filabusi with a 91 % chance of occurring between 10 November and 8 February. During the same period there is a 60 to 80 % probability of a 21 day dry spell occurring. Further down the transect Beitbridge has a 48 to 69 % chance of experiencing a two week dry spell. A 14 to 30 % chance exists for a 21 day dry spell to occur between 10 November and 8 February at Beitbridge.

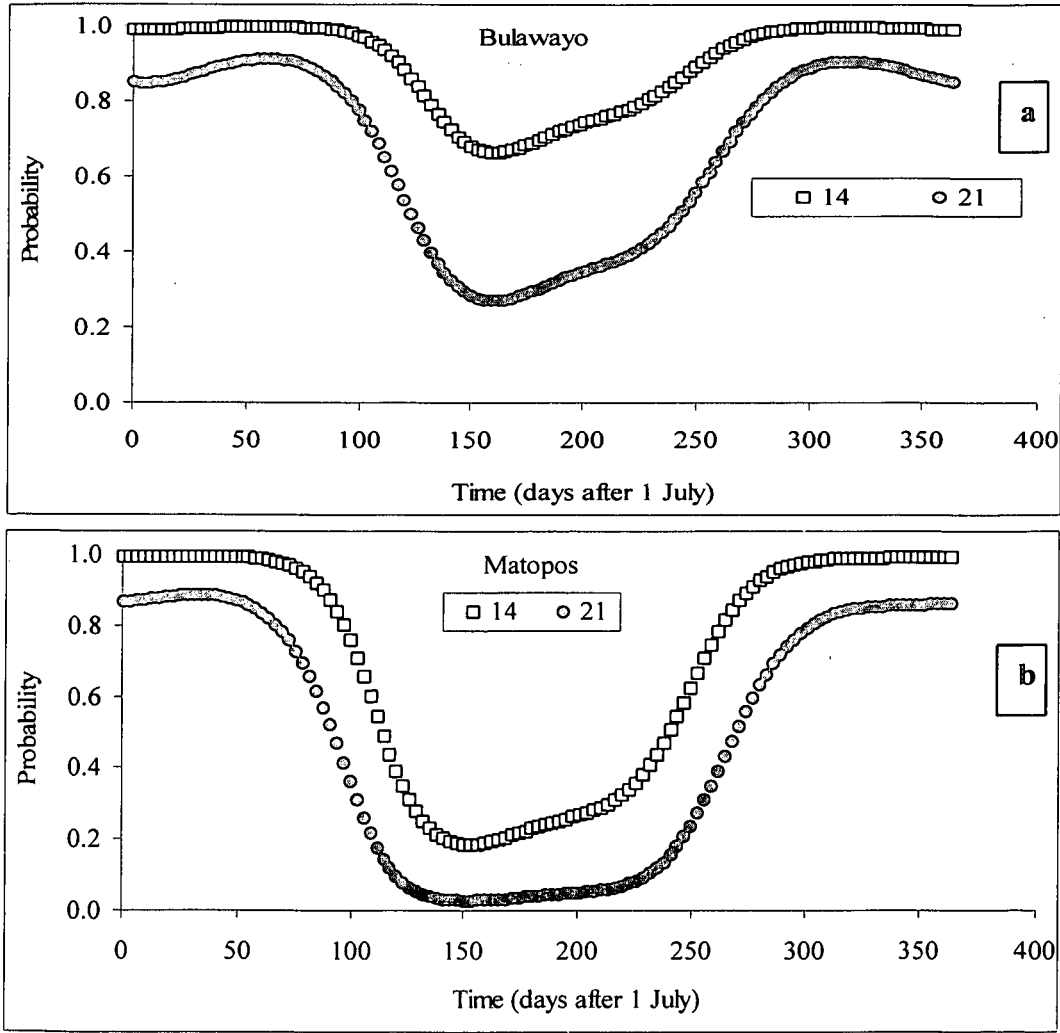


Figure 4.14. Probability of getting 14 and 21 day spells within 30 days from a wet day based on the fitted first order Markov chain probability values for Bulawayo (a) and Matopos (b) meteorological stations in southern Zimbabwe

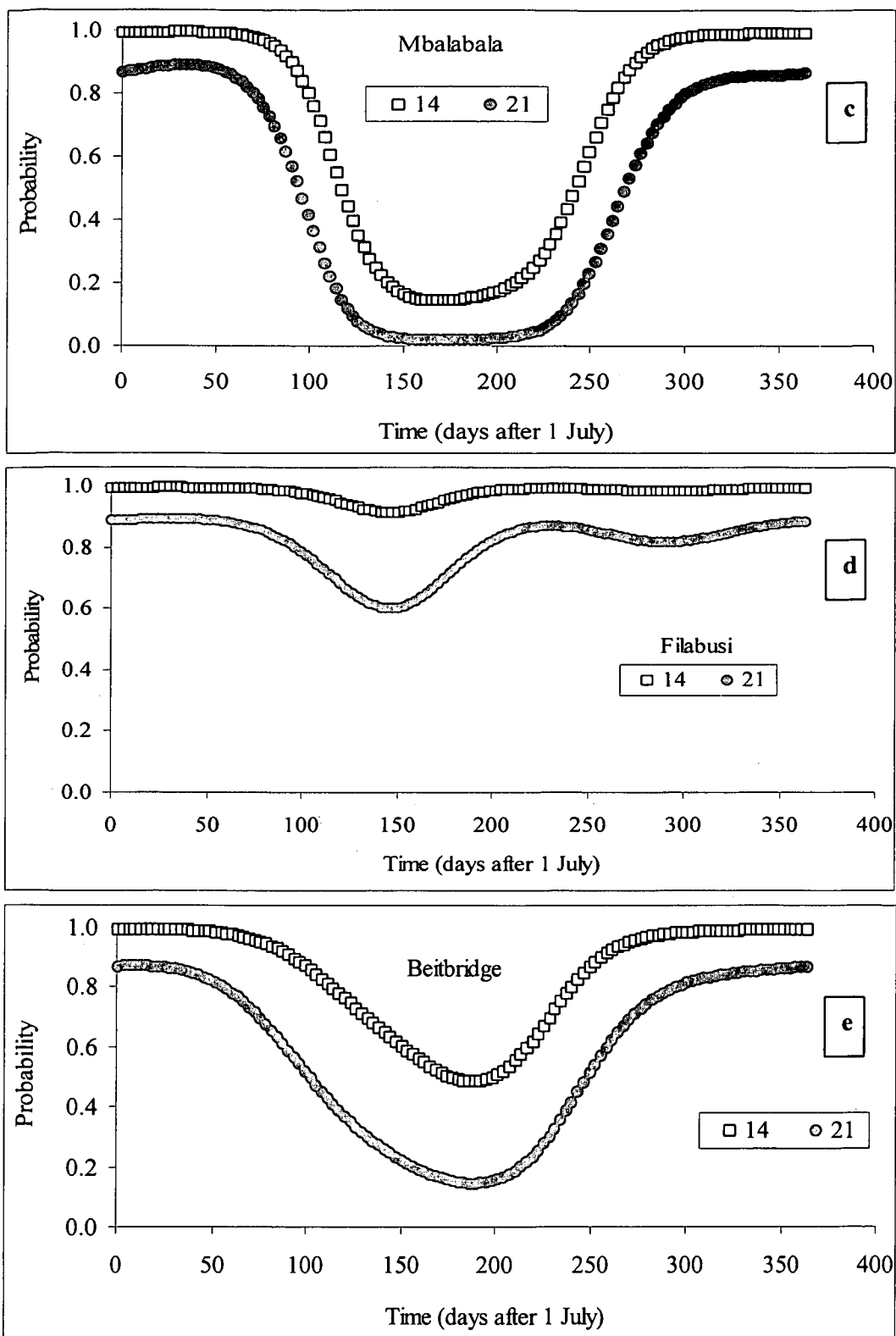


Figure 4.15. Probability of getting 14 and 21 day spells within 30 days from a wet day based on the fitted first order Markov chain probability values Mbalabala (c), Filabusi (d) and Beitbridge (e) stations in southern Zimbabwe

The decrease in probability of getting 14 and 21 day dry spells coincides with the peak rainfall period. The peak rainfall period occurs from December to February (Unganai, 1996). Figures 4.16 and 4.17 reveal that rainfall is more reliable at Matopos and Mbalabala during the December to February peak rainfall period. Rainfall is least reliable at Filabusi where there are 91 and 60 to 80 % chances of getting 14 and 21 day dry spells. At Beitbridge there is a rapid increase in chances for experiencing 14 and 21 day dry spells after receiving rain. This implies that the probability of reduced crop yields or complete crop failure due to soil water deficits is also high at Beitbridge. The probability of dry spells also increases at Bulawayo, Matopos and Mbalabala after 8 February. This coincides with the flowering and grain filling stages of most cereals grown in semi-arid smallholder systems. This poses a major challenge in soil water management in semi-arid rainfed cropping systems.

4.4.8 Cumulative distribution functions for the two halves of cropping season

At all stations there are better prospects of receiving rain in the January-March than October-December period (Tables 4.5 and 4.6; Figs. 4.16 and 4.17). However, three monthly rainfall totals indicate more variation in the second half of the season than the October-December period at all stations (Tables 4.5 and 4.6). This observation suggests that the timing of planting is critical if crops are to reach maturity in semi-arid southern Zimbabwe. There could be seasons with early cessation of rains as observed in 2007/08 (Chapters 7, 9a and 9b) and crops may fail to reach maturity.

At Bulawayo there is a 44 % chance of getting more than 242 mm which is the long term average for the October-December period. There is a 46 % probability of getting more than the long term average rainfall (296 mm) for the January-March half (Table

4.5). There is a 19 % chance of getting 157 mm of rain in both halves of the growing season at Bulawayo. At Matopos there is a 39 % chance of getting more than 248 mm during October-December. The January-March period has a 51 % probability of getting more than 291 mm. There is a 34 % chance of receiving 205 mm in both halves of the growing season (Fig. 4.19). At Mbalabala there is a 48 % chance of getting more than 242 mm during October-December. The January-March period has a 49 % probability of receiving more than 340 mm at Mbalabala. Filabusi has 46 and 41 % chances of receiving more than 214 and 290 mm during October-December and January-March periods respectively. At Beitbridge there is a 25 % probability of getting 97 mm of rainfall during both halves of the growing season. There is 47 % probability of receiving 140 and 176 mm of rain during October-December and January-March periods. In general, the higher probability of getting rainfall during the January-March period give better prospects of crops reaching maturity if planting was done on time with respect to effective planting rains. The timing of farming operations in the first half of season could be critical in order to fully utilize the favourable conditions in the January-March period. These values are useful when the three month seasonal probability forecasts are used by the Department of Meteorology each year.

Table 4.5. Rainfall characteristics for first half (October-December) of the growing season at five stations in semi-arid southern Zimbabwe

Station	Median (mm)	Mean (mm)	Standard deviation (mm)	33 % chance (mm)	66 % chance (mm)
Bulawayo	230	242	91	185	280
Matopos	229	248	94	202	268
Mbalabala	238	242	104	186	272
Filabusi	200	214	94	168	241
Beitbridge	131	140	61	109	156

Table 4.6. Rainfall characteristics for second half (January-March) of the growing season at five stations in semi-arid southern Zimbabwe

Station	Median (mm)	Mean (mm)	Standard deviation (mm)	33 % chance (mm)	66 % chance (mm)
Bulawayo	275	296	141	215	337
Matopos	300	291	155	187	355
Mbalabala	341	340	157	245	414
Filabusi	266	290	152	220	322
Beitbridge	163	176	147	116	198

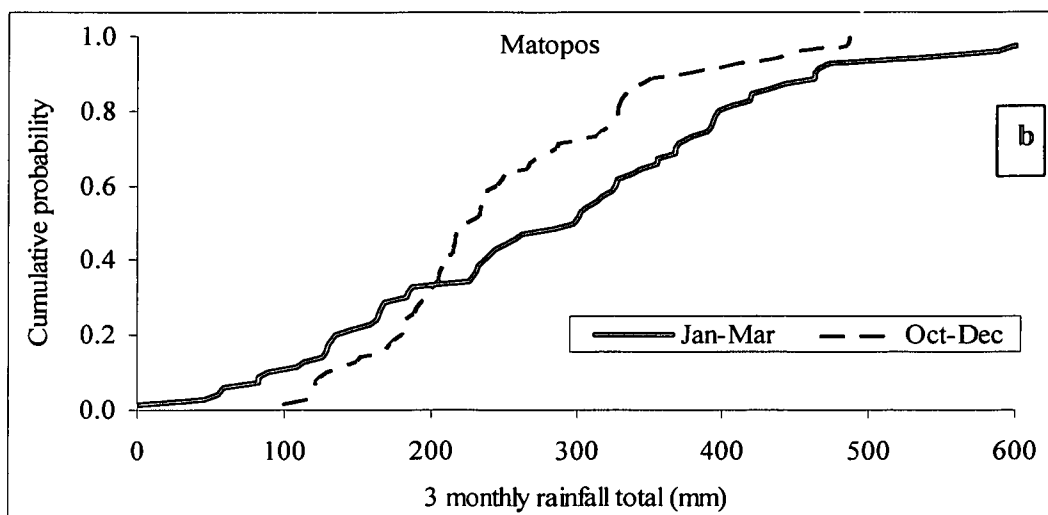
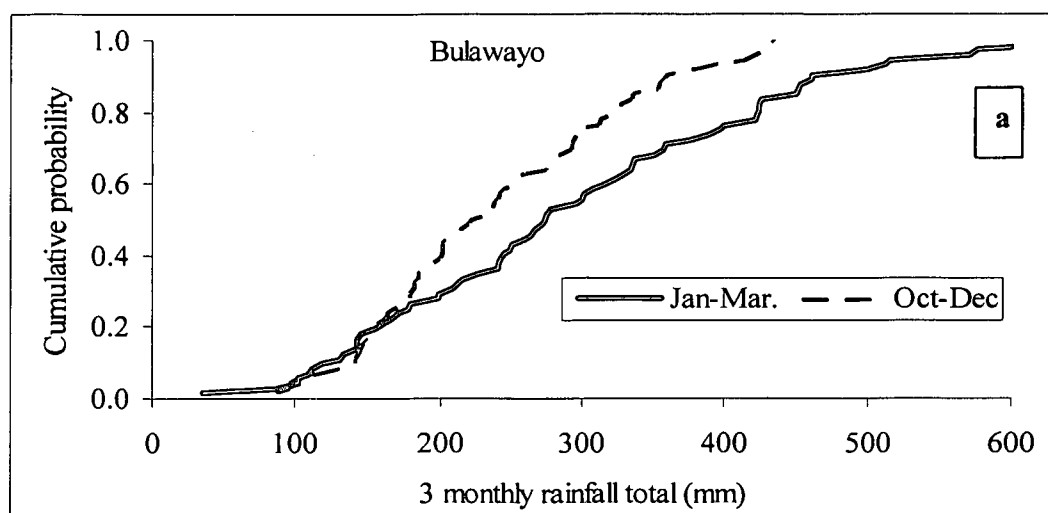


Figure 4.16. Cumulative distribution functions for the first and second halves of the growing season based on three monthly rainfall totals from Bulawayo (a) meteorological station

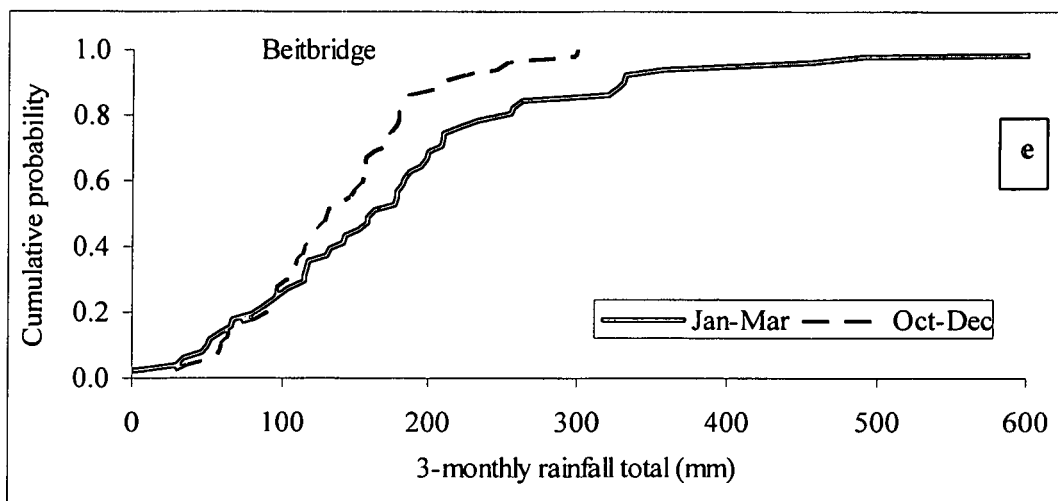
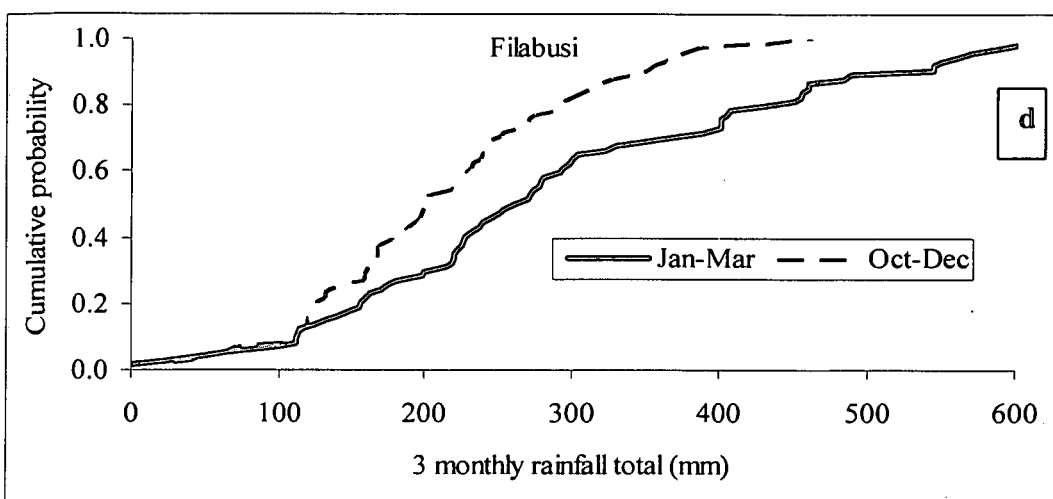
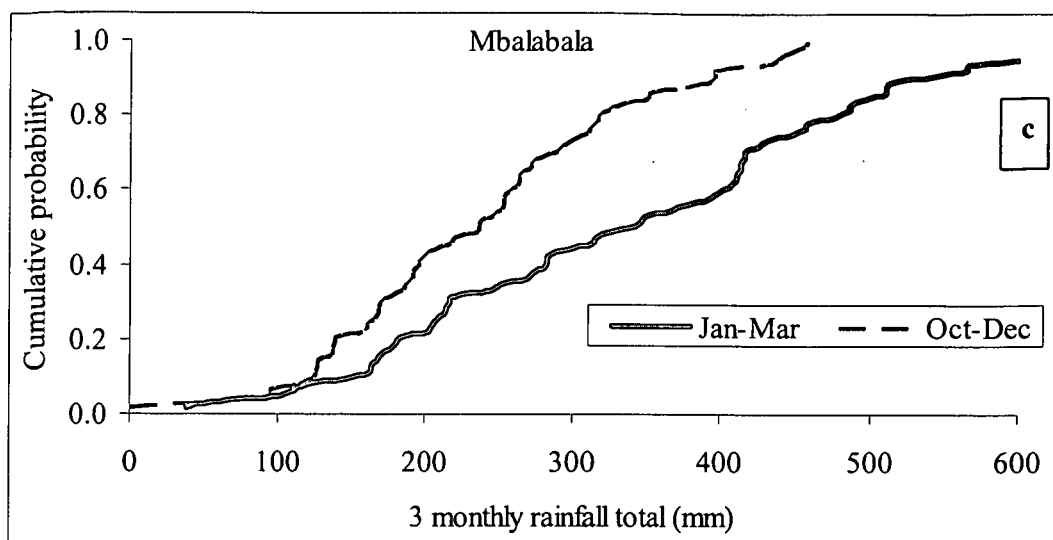


Figure 4.17. Cumulative distribution functions for the first and second halves of the growing season based on three monthly rainfall totals from Mbalabala, Filabusi (d) and Beitbridge (e) meteorological stations

At Bulawayo near-normal (33-66 %) 3-month rainfall totals are 185-280 and 215-337 mm for October-December and January-March periods. The near-normal 3-month rainfall ranges are 202-268 and 187-355 mm for the first and second halves of the season for Matopos. At Mbalabala the below-normal rainfall amounts are 186 and 245 mm for October-December and January-March periods. Data from Mbalabala station showed near-normal rainfall ranges of 186-272 and 245-414 mm for first and second halves of the growing season. The near-normal 3-month rainfall total ranges from 168 to 241 and 220 to 322 mm for October-December and January-March periods at Filabusi. At Beitbridge below-normal 3-month rainfall totals are 109 and 116 mm for October-December and January-March periods.

4.5 Conclusion

There has been no significant change in total annual rainfall over the past 50 to 74 years at five meteorological stations located in the Mzingwane sub-catchment, southern Zimbabwe. The trend in the number of wet days per growing season is similar to the trend in total annual rainfall at all stations reviewed. However, despite the lack of major changes in total annual rainfall significant crop yields reductions and total crop failures are a common feature in semi-arid districts of Mzingwane sub-catchment in southern Zimbabwe. This suggests that the in-season rainfall distribution is playing a stronger part in influencing crop yields than total annual rainfall. This poses a major challenge to farmers, extension agents and researchers to improve rainwater management and storage in semi-arid cropping systems to help through the dry spells.

The start and end, and the subsequent length of the growing season have not changed substantially over the past 50 to 74 years in southern Zimbabwe. The start of growing season was slightly more variable than end of season at Beitbridge (NR V). In both agro-ecological regions timeliness of farming operations could be a potential key to full exploitation of favourable conditions. This is particularly critical given the high chances of 14 and 21 day dry spells from February to the end of season. Rainfed cropping gets more risky as one moves from Bulawayo to Beitbridge based on dry spell analysis conducted in this study. It would be useful to assess the probability of dry spells for the October-December and January-March periods separately as on-farm and on-station experimentation (Chapters 7 and 9) showed that the second half of the season was drier than the first half. The high variation in the three-month rainfall totals implies that there is a risk of crops failing to reach maturity if the timing of the planting date was not good and rainfall ends early as experienced in the 2007/08 growing season.

CHAPTER 5

Soil Water and Fertility Management Practices on Smallholder Farms in Insiza and Gwanda Districts of Semi-Arid Southern Zimbabwe

5.1 Introduction

Smallholder agriculture in the semi-arid areas of southern Africa is largely rainfed, and thus risky, due to high interannual variability and the occurrences of dry spells during the rainy season (Chapter 4; Rockström *et al.*, 2003; Cooper *et al.*, 2008). Potential evapotranspiration exceeds rainfall for more than six months of the year. Rainfall is seasonal and highly variable both within space and time. Annual rainfall for a single site (e.g. Bulawayo) can vary by up to 1000 mm from year to year as a drought year may easily record less than 250 mm, such as the 1990/91 and 2004/2005 season in southern Zimbabwe and Mozambique (Chapter 4; unpublished data, ICRISAT).

In Zimbabwe, water management under rainfed cropping systems has been the focus of many research studies, outside the Limpopo Basin. However, few such investigations have been carried out in the Mzingwane Catchment, which contains the driest areas of Zimbabwe. A major feature of the aridity of the catchment is that the mean annual potential evapotranspiration rates (approximately 1 800 mm) are three to five times the annual rainfall (Chapter 4) suggesting a high potential of soil water loss through evaporation.

In the years with above average rainfall pattern, successful rainfed cropping in the Mzingwane catchment is hampered by the low soil fertility status of the predominantly granite derived sandy soils of the smallholder farming sector. These granitic sands are fragile and inherently low in organic matter, nitrogen and phosphorus (Grant, 1981; Twomlow *et al*, 2006b). The low water holding capacity and low inherent fertility of granite derived sandy soils make them marginal for crop production (Twomlow, 1994).

The purpose of this chapter was to review soil water and fertility management techniques that have been developed for the semi-arid Zimbabwe. The review then identifies soil and water management technologies that have been taken up by the farming communities and those that have been recently introduced in the Mzingwane Catchment of the Limpopo Basin.

5.2 Objectives

The objectives of the study were:

- (1) to review literature on soil and water management technologies developed for the smallholder farming sector;
- (2) to determine the current soil water and fertility management practices which are being used by smallholder farmers in Insiza and Gwanda districts; and
- (3) to identify farmers' perceptions of risk in rainfed agriculture.

5.3 Materials and Methods

5.3.1 *What has agricultural research developed?*

The desk study involved a review of soil water and fertility management technologies developed for the smallholder farming sector. Research work has been conducted on-station and on-farm by the Department of Research and Specialist Services (DRSS) in partnership with other institutions such as University of Zimbabwe and the German Agency for Technical Cooperation (GTZ). Currently soil water and fertility management technologies are being promoted in semi-arid districts of Zimbabwe by Non-Governmental Organisations (NGOs), research institutions and AGRITEX.

5.3.2 *What do farmers say?*

During each focus group meeting held in March 2005, the number of participants, mostly women, averaged between 20 and 40. In Mpumelelo and Masiyepambili villages of Insiza district, 20 and 27 people participated in the group discussions. In Humbane village of ward 17, 23 people took part in the meeting. In Buvuma and Meja villages 31 and 26 people participated in the group discussions while 34 and 40 people were present at Mhalipe and Ngoma meetings. A checklist of guiding questions was developed by researchers before focus group discussions were held. One researcher from ICRISAT facilitated the group discussions while an AGRITEX officer was on hand as a co-facilitator and interpreter. During group discussions notes were recorded on flipcharts by the facilitator while two other researchers recorded the proceedings in notebooks. Each group discussion lasted two to two and half hours in each district.

5.4 Results and Discussion

5.4.1 *What agricultural research has developed*

Good soil water management in rainfed agriculture can be achieved through various tillage, both conventional and reduced, and rainwater harvesting techniques. Various researchers and development agencies have explored *in situ* soil water management technologies for smallholder rainfed agriculture. This section summarizes the findings from previous research studies conducted in Zimbabwe and other southern African countries.

5.4.1.1 *In situ soil water management strategies*

Studies conducted in Zimbabwe and Botswana demonstrated maize and sorghum yield benefits of ploughing to a depth of 0.20-0.25 m compared to the typical depth of 0.10 m (Grant *et al.*, 1979; DLFRS, 1985). Maize and sorghum grain yields increased by 25 to 100 % with ploughing to 0.2-0.25 m depth depending on the season. In these studies the residual effects of the deeper tillage (0.25 m) in terms of reduced bulk densities, and improved root development, crop performance and reduced weed pressures were still apparent in the second season. Similar responses have been observed by other researchers in Tanzania (Northwood and McCartney, 1971). Studies conducted in Botswana clearly demonstrated that double spring ploughing increase crop yields by as much as 71 % across a range of soil types. Similar results have been observed in Zimbabwe also for a range of soil types (Twomlow and Bruneau, 2000).

Minimum tillage has been explored as a soil and water conservation strategy for the semi-arid areas of Zimbabwe. At Makoholi (NR IV) and Domboshawa (NR II), Vogel (1992) evaluated the effect of conventional ploughing, mulch ripping and no-till tied ridging on soil and water loss from fields. The findings from the study by Vogel (1992) showed that mulch ripping retained higher soil water in the topsoil of the sandy soil especially at the beginning of the cropping season. Nyagugumbo (2002) observed similar soil water responses to mulch ripping versus conventional tillage systems on a clay soil at the Institute of Agricultural Engineering (IAE). Mulching protected the soil from erosion and promoted infiltration. Regrettably smallholder farmers have not taken up this technique as mulch material is not readily available. The technology was developed and tested in a non-participatory, top-down approach. The development of the technology did not address the competition for crop residue between crop and livestock enterprises common in the smallholder farming system (Twomlow *et al.*, 2006b).

In the Chiredzi district of south eastern Zimbabwe, tied furrows increased sorghum yields by 4-62 % on a sandy clay loam soil in four out of five seasons (Nyamudeza, 1993). In NRs IV and V of southern Zimbabwe, Nyakatawa *et al.* (1996) observed 22-85 % maize yield increase as a result of using tied furrows compared with planting on the flat. Maize yield response to tied furrows was increased by adding inorganic fertilizer. Addition of inorganic fertilizer increased maize and sorghum yields by 35-115 % and 59-200 % respectively. Widescale promotion of use of low rates of nitrogen fertilizer indicated that cereal yields increase substantially by applying 10 kgNha⁻¹ under the conventional system in semi-arid districts of Zimbabwe (Twomlow *et al.*, 2006a). Trials were

conducted in Gwanda district to determine the effect of livestock manure or basal fertilizer and modified tied ridging on sunflower and sorghum yields (Rusike and Heinrich, 2002). Crop yield results showed that combining manure and inorganic basal fertilizer with tied ridges gives the highest yield benefits (Table 5.1).

Twomlow and Dhilwayo (1999) conducted a study on the effect of conventional ploughing and improved tied ridges and weeding on hydrological properties of three different soil types. Tied ridges created after crop emergence had more soil water than the conventionally ploughed plots. Good weed management ensured maximum utilization of soil water for crop productivity. Weeds compete for the scarce water with crops especially at the beginning of the season. Timeliness of weeding also increase crop yield and water use efficiency irrespective of the tillage practice (Twomlow and Dhliwayo, 1999).

Table 5.1. Effect of combining manure or compound D (8:14:7 – N:P₂O₅:K₂O) with modified tied ridges on crop yield in Gwanda district, after Rusike and Heinrich (2002)

Treatment	Yield (kg ha ⁻¹)
Sorghum + manure + ridges	400
Sorghum + 0 manure + 0 ridges	300
Sunflower + compound D + ridges	550
Sunflower + 0 compound D + 0 ridges	495
Groundnut + ridges	0
Groundnut + 0 ridges	0

Winter ploughing is a technique that has been recommended for decades. It is now the standard recommendation by AGRITEX for the smallholder farming sector. However, deep winter ploughing is still not being practiced in the Insiza and Gwanda districts of the lower Mzingwane catchment. The technique is supposed to involve ploughing to a depth

of 0.2 m soon after harvesting. However, the majority of smallholder farmers plough to a depth of 0.1 - 0.12 m, resulting in the formation of a hardpan within the soil profile. The plough pan restricts root penetration and rainwater infiltration. Crops grown under shallow ploughing cannot withstand extended periods of soil water stress during mid-season dry spells.

5.4.2 The current soil water and fertility management techniques

5.4.2.1 In situ soil water management techniques

A planting basin tillage system has been promoted since 2004/05 growing season across several semi-arid districts of Zimbabwe. During the 2004/2005 season World Vision established trials on planting basins in Gwanda and Beitbridge districts which lie within the Mzingwane catchment. However, these initial trials yielded nothing because of severe drought. However, significant maize yield benefits derived from the use of planting basin system were observed in other districts that lie outside the Mzingwane catchment (Table 5.2). The basin system enabled the farmers to prepare land before the onset of the rains and plant on time following the first effective rains. The basin system also enables resourced constrained smallholder farmers to make more efficient use of limited agricultural resource such as manure and inorganic fertilizers (Twomlow *et al.*, 2008a).

Table 5.2. Rainfall patterns and maize grain yield (kg ha⁻¹) responses to farmer practice and planting basins for 8 districts in southern Zimbabwe in 2004/2005, after Twomlow *et al.* (2006a)

Province	District	Rainfall (mm)	Farmer practice (kg ha ⁻¹)	Basins (kg ha ⁻¹)
Matabeleland North	Hwange	350 - 600	781	1 086
	Lupane	350 - 450	524	796
	Nkayi	530	702	1 134
Midlands	Chirumhanzu	380 - 450	533	1 017
	Zvishavane	380	531	336
Masvingo	Gutu	458	301	395
	Masvingo	260 - 410	603	1 010
	Mwenezi	314	114	120

5.4.2.2 Inter field water management practices

In the Mzingwane catchment of southern Zimbabwe, national and international organizations are promoting the use of inter field rainwater harvesting structures on smallholder farms. The organizations involved include NGOs such as World Vision and Practical Action, AGRITEX, and international research institutes such as ICRISAT. The techniques that are being promoted between fields include dead level contours with underground storage tanks and infiltration pits, and planting basins (Plates 5.1 and 5.2). A dead level contour is pegged at zero gradient and a standard graded contour is pegged at 1:250 gradient (AGRITEX, undated; Hughes and Venema, 2005). The dead level contours harness water originating from the area upslope. The dead level contours vary in size, the minimum having a cross-sectional dimension of 1.5 m width and 0.5 m depth (Mwenge Kahinda, 2004). The length of each contour varies according to the length of the field. Currently there is no quantitative data on crop yield response to soil water contributed by dead level contours with or without infiltration pits (see Chapter 8). Some underground tanks are constructed from bricks (Plate 5.2) and often plastered. They have a capacity of 2 m x 1 m x 4 m and then the water collected from these underground tanks

is used by the household mainly for laundry or watering small gardens (Mwenge Kahinda, 2004).

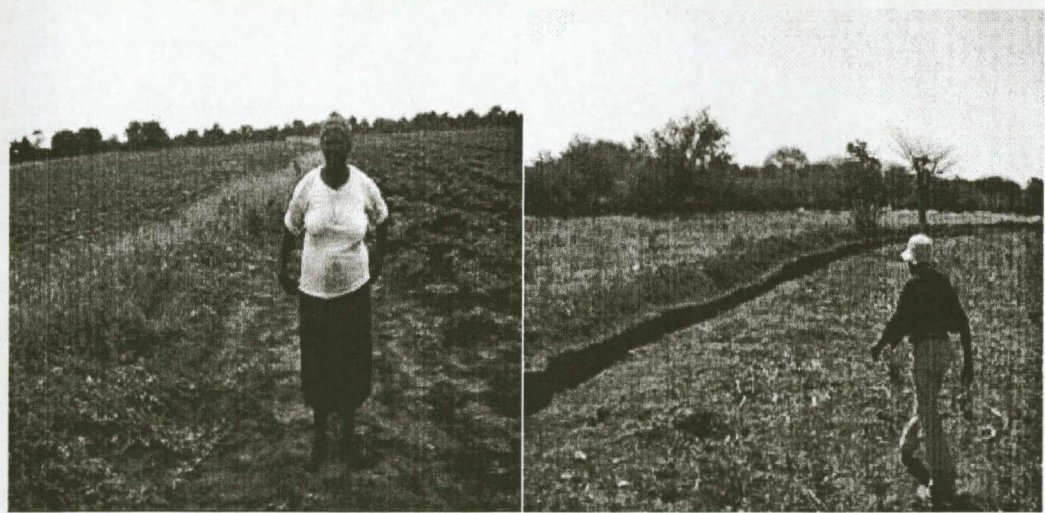


Plate 5.1. Graded and dead level contours found in Insiza and Gwanda districts of Matebeleland South

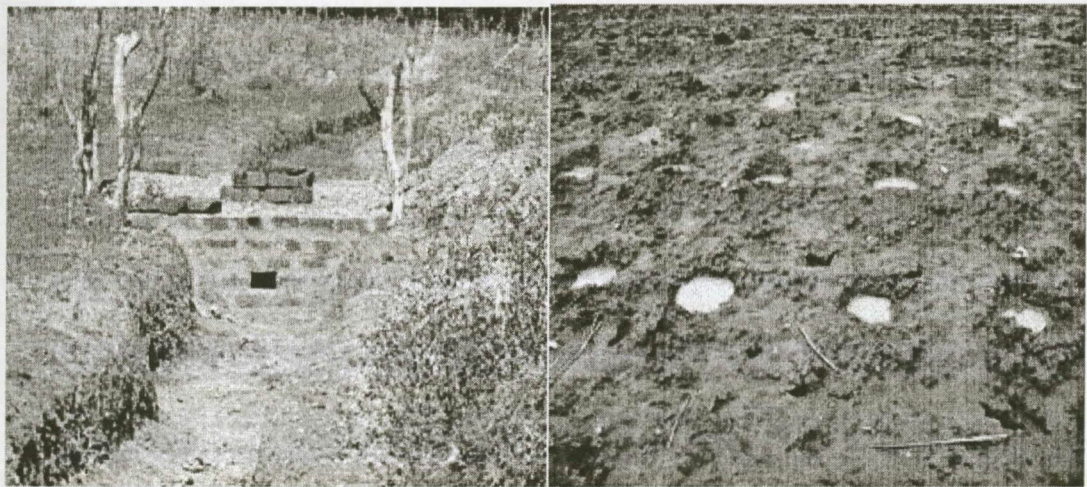


Plate 5.2. Dead level contour with storage tank and planting basins collecting rainwater

5.5 What the farmers said about soil water and fertility management

5.5.1 Insiza district (*Agroecological region IV*)

5.5.1.1 Livestock system

Each household in ward 1 of Insiza district owns at least one of the following animal species: cattle (*Bos indicus*), goats (*Capra hircus*), donkeys (*Equus asinus*), chickens (*Gallus domesticus*) and turkeys (*Melleagris gallopavo*). The livestock numbers vary greatly from household to household with the poorest households owning only chickens. This is consistent with observations made in Insiza district during the 2005/06 and 2007/08 seasons (Chapter 6). Cattle, goats and donkeys are grazed on communal owned rangeland which is highly degraded in ward 1. During the dry season cattle and donkeys graze mainly along the Mzingwane river. Crop residues are either left in the field for livestock to graze or are stacked at the homestead for dry season feeding. World Vision started a programme of stover treatment with urea for dry season feeding. The organization is encouraging farmers to make use of stover that comes from dry land and irrigated crops.

5.5.1.2 Cropping system

5.5.1.2.1 Soil types and crops grown

The total land area owned by households ranges between 1.2 and 3.2 ha. The predominant soil type in the ward is granitic sandy soil with pockets of red clay soil in some cropping lands. Maize is the predominant crop with cowpea, bambara nuts and groundnuts being the common grain legumes. Sorghum is grown on a very limited scale and pearl millet is no longer grown in the area. Participants in the focus group discussions

singled out bird damage as the main factor driving farmers away from growing pearl millet in this area. All crops found in ward 1 of Insiza district can be grown on sand or red clay soils (Table 5.3).

Table 5.3. Major soil types, crop areas and possible yields in a good growing season in ward 1 of Insiza district

Crop	Soils	Area (ha)	Yield (kg)
Maize grain	Red clay, sand	1.2-1.6	1 250-1 500
Sorghum grain	Red clay, sand	0.4-0.6	100-150
Cowpea grain	Red clay, sand	0.1-0.2	15-30
Groundnut pods	Red clay, sand	0.1-0.2	100-250
Bambara nuts pods	Red clay, sand	0.1	25-200

5.5.1.2.2 Land preparation and planting

Less than 5 % of participants in the focus group discussions practiced winter ploughing between cropping periods. The majority of participants only plough their fields after the first effective rains in November/December. The planting period stretches from October to February depending on the rainfall pattern. The growing season in Insiza district (Filabusi) normally starts between 2 November and 24 December (Chapter 4). Planting of maize starts after the first effective rains usually late November to December. However the cereal can be planted as late as mid-February if the rainfall pattern is good. Planting of sorghum starts in October and ends in December. Legumes are planted during November and December.

Maize is either dribbled behind the plough in the third furrow spaced at 0.75-0.9 m or planted in shallow basins opened by a hand hoe. Third furrow planting is a common practice in the smallholder farming system (Twomlow *et al.*, 2006b). Sorghum is either broadcast or dribbled behind the plough. The planting rows of spreading cowpea varieties

are spaced by two furrows apart while the erect varieties are planted in every furrow. Groundnuts and bambara nuts are planted in the second furrow. In-row spacing for maize and sorghum is usually 30 - 40 cm and 20 - 30 cm respectively. In-row spacing for cowpea depends on the growth habit of the variety. Spreading varieties are spaced at 60 cm while erect varieties are spaced at 20 - 30cm. Groundnut and bambara nut are spaced at 10 - 15 cm in the row.

5.5.1.2.3 Weeding

Hand hoe weeding is the common practice although draught animal power owners use cultivators followed by hand weeding to remove weeds close to the crops. All legumes are weeded by the hand hoe. The weeding frequency for all crops depends on the rainfall pattern. In a season with poor rains both cereals and legumes are only weeded once. A season with above average rainfall pattern can force farmers to weed three times especially in cereal fields. Legume fields are weeded twice at the most. The weeding of maize and sorghum stretches from December to March while legumes are weeded between late December and February.

5.5.1.2.4 Soil fertility management

Soil fertility management involves the use of both inorganic fertilizers and manure. The soil fertility amendments are applied to fields where maize is grown, all the other crops are grown on residual fertility. Farmers apply up to 1 600 kg ha^{-1} cattle manure in a farming season following one with good rainfall events. Manure is available in small quantities in ward 1 of Insiza district because households have small herds of cattle. This

is consistent with reports from other districts of Zimbabwe (Ncube, 2007; Mapfumo and Giller, 2001). Cattle manure is applied to the fields between September and October and is left in small heaps which are later spread at ploughing. Goat manure is commonly used in vegetable gardens. Farmers who can afford inorganic fertilizers apply compound D at 20-30 kg ha⁻¹ and 10 to 20 kg ha⁻¹ ammonium nitrate. Basal fertilizer is applied at planting while top dressing is done before tasseling of maize. Top dressing can be delayed because of lack of adequate soil water.

5.5.1.2.5 Harvesting

The harvesting period stretches from March to May with cowpea, which normally matures early, being the first crop to be harvested. Maize and sorghum are harvested during April and May. Farmers are forced to finish harvesting by the end of May because livestock especially cattle are difficult to keep away from the crop residue after this.

5.5.1.2.6 Crop rotation and intercropping

Complete crop rotations are rarely practiced in ward 1 of Insiza district. Participants of the focus group discussions cited lack of adequate legume seed as the main constraint to crop rotations. Maize is only shifted from a particular field if that field becomes infested with the parasitic striga (*Striga asiatica* Kuntze) weed. Striga infested fields are allocated to legumes especially cowpea and groundnuts to try and rid them of the parasitic weed. Pumpkins and watermelons are intercropped with any cereal or legume. Cereal-legume intercropping, if practiced, consists of a combination of maize and cowpea.

5.5.1.2.7 Soil water management

There are no *in situ* soil water management techniques being used by farmers except for a few farmers who have just started participating in the conservation agriculture under the DFID Protracted Relief Programme. Farmers who use the ox/donkey drawn cultivators during weeding pointed out that furrows created during weeding collect rainwater, which later infiltrates into the soil. All participants of the focus group discussions had graded contours as runoff control structures in their fields. Construction of graded contours was compulsory in the pre-independence period. Only a few farmers with draught power are practicing winter ploughing and they pointed out that winter ploughing helps in conserving soil water.

5.5.1.3 Insiza district farmer risk perceptions

During the focus group discussions, prior to the experiments described in Chapter 7, participants were comfortable with classifying farming seasons based on crop production achieved in years with different rainfall patterns. The farming seasons were divided into two categories, good and bad (Table 5.4). The average production is from the total area put under each crop in a particular season per household in each district.

Table 5.4. Characteristics of bad and good farming seasons as observed by farmers in ward 1 of in Insiza district

Crop	Crop production (bad season) (kg)	Crop production (good season) (kg)
Maize grain	15-50	750-1 000
Sorghum grain	0-50	750-1 500
Cowpea seeds	5-12	28-35
Groundnut pods	0	150-200
Bambara nut pods	0	150-200

Participants were asked to classify selected farming seasons and give reasons for the crops that were grown during that time (Table 5.5). Farmers pointed out that they have observed no relationship between the winter temperatures and rainfall pattern of the following farming season. The choice of crop grown depended on the crop species that were available for selection. However, the area under each crop especially maize and sorghum would vary from season to season depending on the rainfall distribution and amount received in the previous summer season. The area under sorghum would be increased in a growing season followed a drought the previous year. The growing seasons classified as bad by the participants were drought years (Chapter 4). The 1999/00 and 2005/06 seasons, classified as good by participants, both did receive above average rainfall in the Mzingwane catchment.

Soil fertility amendments used in ward 1 were basal compound D (8:14:7 – N:P₂O₅:K₂O) and top dressing ammonium nitrate (34.5 % nitrogen) fertilizer as well as livestock manure (Table 5.6). Quantities of soil fertility amendments applied vary from season to season depending on the prevailing rainfall pattern of the summer season. Farmers decrease the quantities of basal inorganic fertilizer or livestock manure applied at land preparation stage if the previous growing season had poor rainfall. The quantities of top dressing fertilizer are adjusted depending on the rainfall pattern of the current growing season, a kind of response farming practice by smallholder farmers in semi-arid southern Zimbabwe.

Table 5.5. Characteristics of different winter and growing seasons and crops grown as reported by farmers in ward 1 of Insiza district

Season	Weather pattern	Crops grown	Reasons for choice of crops grown
1946/47	Drought (bad season), normal winter temperatures	Pearl millet, sorghum (<i>Lundende, Tsweta</i>), pumpkins	Common crops grown and seed was available
1971/72	Below average rainfall but was not very bad season, normal winter temperatures	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts	Common crops grown by the 1960s and 1970s
1979/80	Good season – above normal rainfall, normal winter temperatures	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts	Common crops grown by the 1970s and 1980s
1981/82	Severe drought (bad season), normal winter temperatures	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts	These were common crops grown by the 1980s
1991/92	Severe drought, normal winter temperatures	Maize, sorghum, pumpkins, watermelons, groundnuts, bambara nuts, cowpea	These were common crops grown and previous season was good
1999/2000 (Cyclone Eline)	Good season, above normal rainfall, normal winter temperatures.	Maize, sorghum, pumpkins, watermelons, groundnuts, bambara nuts	These were common crops grown by the 1990s and 2000s
2005/06	Good season, above normal rainfall	Maize, sorghum, pumpkins, watermelons, groundnuts, bambara nuts, cowpea	These were common crops grown by the 2000s

Note: Lundende and Tsweta are traditional sorghum varieties

The major risk factors highlighted by participants were drought, dry spells, lack of appropriate seed varieties and inadequate seed supply, and lack of animal draught power. Participants ranked the risk factors according to how severe they can impact the household food security (Table 5.7). Participants unanimously agreed that drought had the most severe impact on food availability in all households in ward 1. Drought is a recurrent event in Insiza and Gwanda districts as shown from the rainfall analysis in Chapter 4.

Table 5.6. Soil fertility amendments applied during bad and good seasons by farmers in ward 1, Insiza district

Soil fertility amendment	Quantity applied in	
	bad season	good season
Manure	600-800 kg ha^{-1}	1 200-1 600 kg ha^{-1}
Compound D	0	40 kg ha^{-1}
Ammonium nitrate	0 – 25 kg ha^{-1}	60 kg ha^{-1}

Table 5.7. Risk factors and their severity on household food security as identified by farmers in ward 1 of Insiza district

Risk factor	Rank
Drought	1
Dry spells	2
Lack of draught power	3
Lack of appropriate and adequate seed	4

4 = least severe; 1 = most severe

5.5.1.4 Coping strategies in ward 1 of Insiza district

The survival strategies used by farmers in the area during periods of drought were to divert attention and look to off farm activities such as gold panning and selling of livestock. Gold panning, although illegal in Zimbabwe, is the main survival activity during drought years as ward 1 of Insiza district lies in the gold belt of Zimbabwe. Farmers-turned-miners sell their gold to legal and/or illegal gold dealers who frequent

their area. The major livestock species sold during periods of drought are cattle and goats. Goats are normally sold first with cattle being sold when school fees or medical bills have to be paid. Livestock are sold to private abattoirs or the Cold Storage Company of Zimbabwe. Remittances, money sent home by household members working in cities or other countries, cushion households especially those with family members working in South Africa, Botswana and other countries. Household members working outside Zimbabwe bring cash, groceries, clothes, household furniture and even building materials when they return for visits to the family.

5.5.2 Gwanda district (Agroecological region V)

5.5.2.1 Livestock system

More than 90 % of the participants owned at least one of the following livestock species: cattle (*Bos indicus*), goats (*Capra hircus*), sheep (*Ovis aries*), donkeys (*Equus asinus*), chickens (*Gallus domesticus*) and turkeys (*Melleagris gallopavo*). Cattle, goats, sheep and donkeys graze on communal pastures but cattle are sometimes also taken to rented grazing paddocks (*Mulageni*) during the dry season. Donkeys are always grazed on the communal pastures even in years of severe drought. They are sometimes fed on the crop residues that were stacked at the side of the kraal from the crop field. World Vision and Practical Action have started forming farmer groups to process stover collected after harvesting into stock feed for dry season feeding.

5.5.2.2 Cropping system

5.5.2.2.1 Soil types and crops grown

The major soil type is sand (*inhlabathi in Ndebele*) with small areas having black clay (*isidaka in Ndebele*) and red clay (*isibomvu in Ndebele*). Some areas have sodic soils (*isikwakwa in Ndebele*) and these are not suitable for cropping, however, some participants said they grow pearl millet on sodic soils. The main cereal crops grown are pearl millet, sorghum and maize (Table 5.8). The most common grain legume is cowpea with groundnuts and bambara nuts being grown to a lesser extent. Pumpkins and watermelons are intercropped with cereals and a few farmers also grow sunflower and sweet potatoes.

Table 5.8. Major soil types, crop areas and possible grain production in a good growing season in Gwanda district

Crop	Soil type	Area (ha)	Crop production (kg)
Pearl millet grain	Sand, red clay, black clay, sodic	0.8-1.2	750-1 000
Sorghum grain	Sand, red clay, black clay	0.8-1.6	1 250-1 500
Maize grain	Sand, red clay, black clay	0.8-1.6	250-500
Groundnuts pods	Sand, red clay, black clay	0.1	100-400
Cowpea grain	Sand, red clay, black clay	0.1	25-100
Bambara nuts pods	Sand, red clay, black clay	0.1	50-250

5.5.2.2.2 Land preparation and planting

The total land area owned by households ranges from 3.2 to 4.9 ha. Although winter ploughing is recommended for Gwanda south, none of the participants practiced winter ploughing either for soil water conservation or for incorporating crop residue and weeds,

at the time of these discussions in March 2005. Conventional ploughing of the land starts in November/December each year after the first effective rainfall and when draught animals are strong. Farmers usually waste initial soil water because draught animals are very weak as a result of inadequate feeding during the dry season.

Planting of cereals starts after the first effective rains usually late November to December. The growing season in Gwanda district normally starts in December. Planting of maize can stretch from December to February if the season is promising to be a good one like the 2005/06 cropping season. Small grains (sorghum and pearl millet) are planted before the end of December even if the season promises to be good. More than 80 % of the participants pointed out that they also do dry planting of pearl millet from mid-October onwards before the first rain occurs. Legumes are also planted during November and December each year at the onset of the rains.

Maize is planted in every 3rd furrow while sorghum and pearl millet are either broadcast or dribbled behind the plough. In a year with low rainfall farmers prefer dribbling all cereals behind the plough than planting in furrows opened by a plough. Participants pointed out that in seasons with poor rainfall distribution during the planting period, cereal crop establishment is better where the seed was dribbled behind the plough than in furrows opened by a plough and covered with hand hoes. Maize is spaced at 30 – 40 cm within the rows. In-row spacing for sorghum and pearl millet varies between 30 and 40 cm. Rows of cowpea and bambara nuts are spaced two furrows apart. For bambara nuts this facilitates earthing up at pod development stage. Groundnut is planted in every

furrow. In-row spacing for groundnut and bambara nuts varies between 15 and 20 cm while cowpea is spaced at 30 – 40 cm.

5.5.2.2.3 Weeding

Weeding starts in December every year especially in maize fields. Sorghum and pearl millet are usually weeded twice, between late December and February. Maize is weeded thrice especially in a season with above average rainfall pattern. The first weeding of maize is done in December followed by a second weeding in January or February. A third weeding in maize fields is done between the end of February and March. Legumes are weeded once, usually in January, except for groundnut which can have a second weeding between February and March in a season with good rains.

Draught power owners use animal drawn cultivators as well as hand hoes for weeding cereals. When an animal drawn cultivator is used for weeding, farmers follow the cultivator with hand hoes cleaning up any remaining weeds especially in the in-row spaces. Non-draught animal owners can only use the hand hoe for weeding both cereals and legumes.

5.5.2.2.4 Soil fertility management

The majority of participants appreciated the importance of managing soil fertility in their farming system. However, livestock manure and inorganic fertilizers are not used despite evidence of poor soil fertility such as declining crop yields and the high striga infestation on most farms. Farmers have experienced crop *burn* in some growing seasons when they

have used manure and inorganic fertilizer and this makes them cautious. Livestock manure and fertilizer are applied in gardens where soil water availability is guaranteed. Those farmers that once applied manure or fertilizer to crops had done so basing their decision on the rainfall distribution during the previous farming season. Farmers believe that the legumes they are growing are improving the fertility of their soils.

5.5.2.2.5 Harvesting

Harvesting of cereal crops stretches from April to June and legumes are also harvested at the same time. Harvesting of cowpea dry pods starts in March and continues up to May depending on the variety. Local varieties are usually the last to be harvested. Farmers use natural indicators like leaf colour of certain trees to make decisions on when to start harvesting certain crops. In Gwanda farmers use the '*Umvimila*' tree as a signal of when to harvest legumes especially bambara nuts. When the leaves of a '*Umvimila*' tree start turning yellow, it is the ideal time to harvest groundnuts and bambara nuts if these legumes were planted between November and December.

5.5.2.2.6 Crop rotation and intercropping

Participants pointed out that crop rotation is only triggered off by the appearance of striga. Striga usually appears in a season with a good rainfall pattern and this usually happens after five or more years of continuous growing of a cereal crop in a given field. Those that practice rotation pointed out that the rotation usually does not cover the whole area that was under a cereal crop because of smaller legume areas. Usually legumes are planted on less than 25 % of the cropped area in one season. Allocation of less land for

growing legumes has also been reported in other districts of southern Zimbabwe (Ncube, 2007). Maize and sorghum are usually intercropped with legumes (bambara nuts, cowpea and groundnut). The intercrops are usually arranged such that a row of cereal alternates with two rows of a legume. On some farms single cereal and legume rows alternate. Sunflower, watermelons and pumpkins are intercropped with any cereal or legume.

5.5.2.3 Soil water management

5.5.2.3.1 Ward 17

There were no in-field soil water management practices in ward 17 in March 2005. All participants had dead level contours with and without infiltration pits. Farmers have observed that crops on the downslope side and close to the dead level contour with infiltration pits take longer to show water stress in the event of a dry spell. Participants unanimously agreed that dead level contours are suitable for both wet and droughty seasons. In a wet season there would be more rainwater to collect resulting in a good crop while in a droughty year the little rainwater received is captured by the dead level contours and infiltration pits.

Participants pointed out that they took part in the dead level contours project because Practical Action for Southern Africa was providing them with tools and food as the farmers constructed the contours. The NGO encouraged them to form groups to assist each other in the construction of the contours. The challenge facing the dead level contours project is that it is labour intensive. An ordinary family in Gwanda south has two to four able-bodied people and construction of the contours becomes an impossible

task for the family alone. The tools distributed by Practical Action have sparked friction within some groups in all wards where focus group discussions were held.

5.5.2.3.2 Ward 18

The inter-field water management practices were dead level contours with and without infiltration pits on most fields in ward 18. A few farmers did not have any inter-field soil water management practices. None of the participants had in-field soil water management practices. The dead level contours with infiltration pits that are present are being promoted by NGOs. Farmers are organized in groups of 20 and they are given the implements such as picks, shovels and wheelbarrows to use by Practical Action. World Vision has been promoting the dead level contours through its Food for Work Programme since 2004. Some farmers report that the crops look less water stressed in the fields with the dead level contours but the yield benefits are still to be realized. Farmers suggested improvements like reducing the field width through digging the dead level contours closer to each other and making the infiltration pits larger.

5.5.2.3.3 Ward 20

There were no in-field soil water management practices being used on farmers' fields in 2005. However, a few farmers were using inter-field structures such as dead level contours and *fanya juus*. These practices were being used by less than 20 % of the people who took part in the focus group discussions. Those farmers implementing the dead level contours and *fanya juus* said they had received training from World Vision under the Food for Work Programme in 2004. Those farmers that had dug the dead level contours

and infiltration pits said they had not yet seen any crop yield benefits from the dead level contours, hence they were reluctant to undertake the strenuous work when crop yield benefits were not guaranteed. Farmers who had dead level contours on their fields suggested improvements of the dead level contour structure such as bunding the contour so that more water could be collected in the contour during heavy rainfall events. None of the participants in the focus group discussions were using winter ploughing as a soil water management strategy.

5.5.2.4 Gwanda district farmer risk perceptions

Farmers classified good and bad seasons based on crop production as had been done in Insiza district (Table 5.9). The decision to grow a certain crop depends on the rainfall characteristics of the previous season. After a drought, farmers said that they grew more drought tolerant crop varieties especially local varieties and decreased the area under maize. From the farmers' assessment of different seasons there was no relationship between winter temperatures and the rainfall pattern of the following farming season (Table 5.10).

Table 5.9. Crop production in good and bad farming seasons in Gwanda district

Crop	Crop production	
	Bad season	Good season
Pearl millet grain	0 – 50 kg	300-400 kg
Maize grain	0	500-725 kg
Sorghum grain	0 – 50 kg	1 000-1 500 kg
Cowpea seeds	0	10 kg
Groundnuts pods	0	100-150 kg
Bambara nuts pods	0	150-200 kg

The majority of participants voted that crop failure in most years was caused by (i) low

and erratic rainfall; (ii) delayed start of the cropping season due to late rains; (iii) long dry spells especially in January when the crop is entering the reproductive phase; and (iv) inappropriate crop varieties (Table 5.11). Inappropriate crop varieties usually come through donations by NGOs, church organizations or the Grain Marketing Board (GMB).

Table 5.10. Characteristics of different winter and growing seasons and crops grown as observed by farmers in Gwanda district

Season	Weather pattern	Crops grown	Reasons for choice of crops
1946/47	Severe drought, below average rainfall, normal winter temperatures	Pearl millet, sorghum, pumpkins, watermelons	These were common crops grown by then
1947/48	Good rain season, normal rainfall pattern, normal winter temperatures	Pearl millet, sorghum, pumpkins, watermelons	The season 1946/47 was very dry. Local varieties such as <i>Tshweta</i> and <i>Lundende</i> sorghum were grown
1971/72	Below average rainfall, normal winter temperatures	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts	These were common crops grown by the 1970s
1991/92	Drought, normal winter temperatures	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts, sunflower	These were common crops grown by the 1990s
1999/2000 (Cyclone Eline)	Very good season, above normal rainfall, normal winter temperatures.	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts, sunflower	These were common crops grown by 2000
2005/06	Above normal rainfall	Maize, pearl millet, sorghum, pumpkins, watermelons, groundnuts, bambara nuts, sunflower	These were common crops grown now

Note: Lundende and Tsweta are traditional sorghum varieties grown in southern Zimbabwe

Table 5.11. Risk factors and their severity on household food security as identified by farmers in Gwanda district

Risk factor	Rank
Low and erratic rainfall	1
Dry spells	2
Inappropriate crop varieties	3
Late start of season	4

1 = most severe; 4 = least severe

5.5.2.5 Copying strategies for farmers in Gwanda district

Households in wards 17, 18 and 20 survive by generating cash from livestock sales, selling mopane worms from January to April, and remittances during periods of drought induced hardships. All types of livestock are sold including donkeys when there is severe drought. Goats and sheep are normally sold first and cattle follow especially when food has to be bought and school fees paid. Poultry are sold most of the time whether there is drought or not. Harvesting and selling Mopane worms is a big activity during the time when the caterpillars are available from January to April. Households sell the worms to other villagers and to buyers who come from Bulawayo and other cities. Recently an NGO called SAFIRE formed community clubs that buy mopane worms from villagers and resell in cities. The mopane worms also have lucrative markets further afield in the Democratic Republic of Congo and Zambia. However, Mopane worms breed better when the rainy season is average to above average. During times of severe drought these worms are only available in very small populations. Almost every household in wards 17, 18 and 20 of Gwanda district has a family member working in one of the Zimbabwean cities or other countries such as South Africa and Botswana. The support comes on a regular basis in the form cash, clothes or groceries.

5.6 Conclusion

Despite the evidence of crop yield benefits derived from using some of the research developed technologies, smallholder farmers in Insiza and Gwanda districts have not adopted the available technologies. In ward 1 of Insiza district the only soil water management technique used are the poorly maintained graded contours which direct excess water from the field. In Gwanda district dead level contours, infiltration pits and underground tanks are the technologies smallholder farmers are using for rainwater harvesting in the field. These inter-field structures are being promoted predominantly by Practical Action who provide farmers with implements for constructing the rainwater harvesting structures.

The use of soil fertility amendments such as inorganic fertilizers and manure is still very low in Insiza and Gwanda districts of the Mzingwane catchment. Only the smallholder farmers in the relatively wetter Insiza district (NR IV) are using manure and inorganic fertilizers. The farmers in Gwanda district are not using manure despite having more manure from cattle and goats compared with Insiza district. The farmers fear crop burn by inorganic fertilizer and manure, and they only apply the soil fertility amendments in vegetable gardens where soil water is guaranteed through watering by buckets.

Farmers in both districts consider lack of rainfall to be their biggest challenge. Drought was ranked as the major challenge to successful cropping in ward 1 of Insiza district. The smallholder farmers in Gwanda district ranked low seasonal rainfall and its distribution during the growing season as the major challenges to successful rainfed crop production.

The mid-season dry spells were ranked as the next serious constraint to cropping in both Insiza and Gwanda districts. During the periods of drought, the farming families in Insiza and Gwanda districts rely on off-farm activities for livelihoods. In Insiza district gold panning is the main income generating activity while selling mopane worms dominates in Gwanda. Households also rely on selling livestock in years of severe drought. Households also rely on remittances as each household as a family member working in the cities of Zimbabwe or more importantly, in neighbouring countries such as Botswana and South Africa.

CHAPTER 6

Farm Characteristics and Evaluation of Soil Water and Fertility Management Options for Smallholder Semi-Arid Cropping Systems

6.1 Introduction

Smallholder farming systems in sub-Saharan Africa comprise crop and livestock sub-systems with crops benefiting from livestock through manure and draught power. The livestock derives feed and bedding from the crop residues. Crop and livestock production on these smallholder farms is controlled by a wide range of socio-economic conditions and access to resources (Defoer, 2002). Developing technologies aimed at increasing productivity of smallholder farming systems is meaningless without input from farmers (Defoer *et al.*, 2000).

A number of technologies have been developed for the smallholder farming system. These have been developed from studies on soil water and fertility management, weed management and crop varieties (Vogel, 1992; Nyamudeza, 1993; Nyakatawa *et al.*, 1996; Twomlow and Bruneau, 2000). However, levels of adoption have remained disappointingly low despite the benefits shown from experimentation. The reasons for lack of adoption vary from household to household with different farming objectives, wealth status, labour availability and access to inputs reported as some of the major drivers to technology uptake (Petersen *et al.*, 1999).

Despite the lack of technology adoption, research and development work still needs to continue as more challenges crop up in the smallholder farming sector. More recently, International research organisations, NGOs and extension service departments have embarked on the promotion of conservation agriculture in semi-arid smallholder farming areas of Zimbabwe. The

farming practices being promoted involve the use of both ripper and planting basin tillage systems. At the end of three seasons of testing these technologies on their farms, smallholder farmers in Gwanda and Insiza districts of southern Zimbabwe had an opportunity to evaluate the performance of the four tillage systems. This chapter presents results on the characterization of agricultural resource allocation using resource flow mapping and evaluation of tillage systems through focus group discussions.

6.2 Objectives

The overall objective was to allow farmers to evaluate soil water and fertility management options that are being promoted in Gwanda and Insiza districts. The specific objectives of the study were:

- (1) to identify agricultural resource allocation on smallholder farms in semi-arid southern Zimbabwe; and
- (2) to evaluate the performance of single and double conventional ploughing, ripper and planting basin tillage systems after three growing seasons.

6.3 Materials and Methods

6.3.1 Resource flow mapping

Resource flow maps were drawn following guidelines outlined by Defoer *et al.* (2000). The farm was considered the unit of analysis, comprising three sub-systems namely household, cropping and livestock. The flow of agricultural resources from one sub-system into another was indicated by arrows on the map. During the mapping exercise each farmer drew maps of their homestead and field on the ground. The maps indicated where various components of the farm were located

and types of crops grown in the different fields during 2005/06 and 2007/08. The maps were then transferred onto manila sheets by researchers. Each farmer related sources and quantities of seed for each crop grown and soil fertility amendments applied to different fields. The farmer was asked to give an estimate of production obtained for each crop type grown. The flows of nutrients, crop harvests and other resources on the farm were indicated on the map by arrows of different line styles. After the drawing the map, the farm was toured to confirm the outlined set-up and components of the farm given by the farmer (Plate 3.2). Farmers also participated in the exercise documenting the overall cropping calendar for each district.

6.3.2 Focus group discussions

A checklist of guiding questions was developed by researchers before focus group discussions were held (Appendix 1). One researcher from ICRISAT facilitated the group discussions while an AGRITEX officer assisted with facilitation and translation. During group discussions notes were recorded on flipcharts by the facilitator while two other researchers recorded proceedings in notebooks. Each group discussion lasted two to two and half hours in each district.

6.4 Results and Discussion

6.4.1 Resource flow mapping

6.4.1.1 Resource endowment

The resource endowment analysis showed that four of 14 households had no cattle and for those with cattle, the average number of cattle was 11 in 2005/06 and eight in 2007/08 per household (Table 6.1). The Magaya family of Humbane village in Gwanda owned 40 cattle and all the cattle were grazed at a rented paddock (*mulageni*) in the same district. The cattle numbers

obtained from this study were within similar ranges as those reported by Ncube (2007) in Tsholotsho district through a resource flow mapping study and Homann *et al.* (2007) in a survey in Beitbridge, Matobo, Binga and Nkayi districts of Zimbabwe. In the semi-arid Chivi district cattle numbers were lower as reported by Chibudu *et al.* (2001) ranging from one to eight for different resourced households. A resource flow mapping study by Zingore (2006) also revealed that smallholder farmers in the more humid northern districts of Zimbabwe own 10 to 16 cattle. Goat numbers averaged between 18 and 25 per household during the two seasons studied. The highest number of goats, 76, was recorded at the farm of John Ncube while the Mlilo family also in Gwanda district had 28 donkeys. More goats and donkeys per household were recorded at end of the 2005/06 season than the 2007/08 season (Table 6.1) and these numbers were higher than those reported for Tsholotsho district by Ncube (2007). Goats are a main source of income in Gwanda and Beitbridge districts of southern Zimbabwe (Homann *et al.*, 2007). Donkeys are the main source of draught power in Gwanda district with only a few households using oxen for agricultural land preparation. Only the Magaya family in Gwanda district used oxen for draught power while in Insiza district the main source of draught power was cattle.

The farming equipment analysis showed that each household had at least one plough and four hand hoes (Table 6.1). Ownership of these farming equipment meant that each household could prepare land for cropping through conventional tillage or embark on the use of planting basins. Family size averaged eight people per household at the end of 2005/06 and seven after the 2007/08 season. The size of families ranged from six to 13 people per house at the end of 2005/06 and four to 10 in 2007/08 growing seasons with an average of three family members providing labour for agricultural activities. The household size was generally similar to results

from Tsholotsho, Chivi and Murewa districts of Zimbabwe (Chibudu *et al.*, 2001; Zingore, 2006; Ncube, 2007).

Table 6.1. Farmer resource status as an average of Gwanda and Insiza districts of southern Zimbabwe

Criteria	2005/06 season	2007/08 season
Cropped area (ha)	not measured	2.1 (0.34)
Livestock numbers		
Cattle	11 (3.8)	8 (2.5)
Goats	25 (7.4)	18 (6.8)
Donkeys	7 (2.7)	5 (1.6)
Chickens	12 (2.8)	11 (2.9)
Asset numbers		
Plough	2 (0.3)	1 (0.2)
Scotch carts	1 (0.2)	1 (0.2)
Hoes	4 (0.5)	4 (0.4)
Wheelbarrows	1 (0.3)	1 (0.4)
Bicycles	2 (0.6)	1 (0.4)
Family size	8 (0.7)	7 (0.6)
Number of members providing labor	3 (0.31)	3 (0.27)
Grain required (kgyear ⁻¹)	912 (82.4)	829 (69.5)
Grain produced (kgyear ⁻¹)	891 (231)	262 (85.3)
Surplus/deficit (kgyear ⁻¹)	-21 (221)	-567 (113)

The numbers in brackets indicate standard errors of means.

Family size includes adults and children.

The major farming objective at all households was to provide enough food for the family. Cereal grain requirements per household per year were average 912 kg in 2005/06 and 829 kg in 2007/08. In both seasons households had a grain deficit despite 2005/06 being a good agricultural season and 2007/08 having fair rainfall distribution in the first half of the season. Grain surplus/deficit was calculated as the difference between household annual grain requirement and grain harvested at end of each season from the main cereals namely maize, sorghum and pearl millet. All farms had a grain deficit in both 2006 and 2008 and this is typical of semi-arid areas of Zimbabwe. The severity of the situation in 2008 could have been

aggravated by a general decline in the Zimbabwean economy and the political unrest, meaning that little seed was available to plant in 2007. Surveys conducted by ICRISAT have revealed that the majority of households in semi-arid southern Zimbabwe rarely produce enough grain to meet their own household requirements (Twomlow and Rohrbach, 2006). Crop yields are always poor regardless of rainfall and this has also been reported in other districts of Zimbabwe (Ncube, 2007).

6.4.1.2 Flow of agricultural resources

The flow of agricultural resources on two farms, one representing farmers hosting research trials and another one representing farms without trials, is presented and discussed in this section, others are given in Appendix 6.2. The resource flow maps show how agricultural resources were allocated during the 2007/08 growing season and crop produce harvested from each field. Mr. John Ncube's farm as illustrated in Figure 6.1 is located in Fumukwe village of ward 17 in Gwanda district. The family of Mr. John Ncube comprises six adults and three primary school going children. Two of the six adult family members are working in South Africa and occasionally come to Fumukwe at the end of some months. Mr. John Ncube's total area is about five hectares. The 72 year old, Mr. John Ncube started interacting with researchers at the beginning of 2005/06 growing season and was not related to any member of the research team. Before the arrival of researchers in 2005/06 season, Mr. John Ncube had already been using livestock manure and inorganic fertilizer particularly as a topdressing fertilizer. Cattle and goat manure are the major soil fertility amendments used at Mr. John Ncube farm. Farmers who have had positive experiences with manure and inorganic fertilizer continue to use them despite the lack of proper recommendations about application rates for semi-arid areas. The widely

promoted micro-dosing program in semi-arid areas of Zimbabwe has exposed farmers to the use of low rates of inorganic fertilizers (Twomlow *et al.*, 2008b). Before the start of the 2007/08 growing season, Mr. John Ncube bought 25 kg of urea from a neighbour who had received the fertilizer through World Vision's agricultural relief program. Researchers gave Mr. John Ncube 11 kg of ammonium nitrate which was to be applied to the maize on the research field. Urea was applied to maize while sorghum and pearl millet received neither inorganic fertilizer nor livestock manure during the 2007/08 growing season. Results from a survey by Chibudu *et al.* (2001) in semi-arid Chivi district showed farmers' preference of applying manure to maize fields. According to Mr. John Ncube, cattle and goats provided 20 carts of manure each and all the manure was broadcast onto the maize fields before ploughing operations were carried out. Chicken manure and household waste were applied to the vegetable garden. All maize residues were collected and stacked at the kraal for dry season cattle feed. Grain legume residues were fed to the goats with donkeys having no stover allocation. All cereal and legume grain produced was consumed at the household with pearl millet providing the bulk of cereal grain harvested at the end of 2007/08 season.

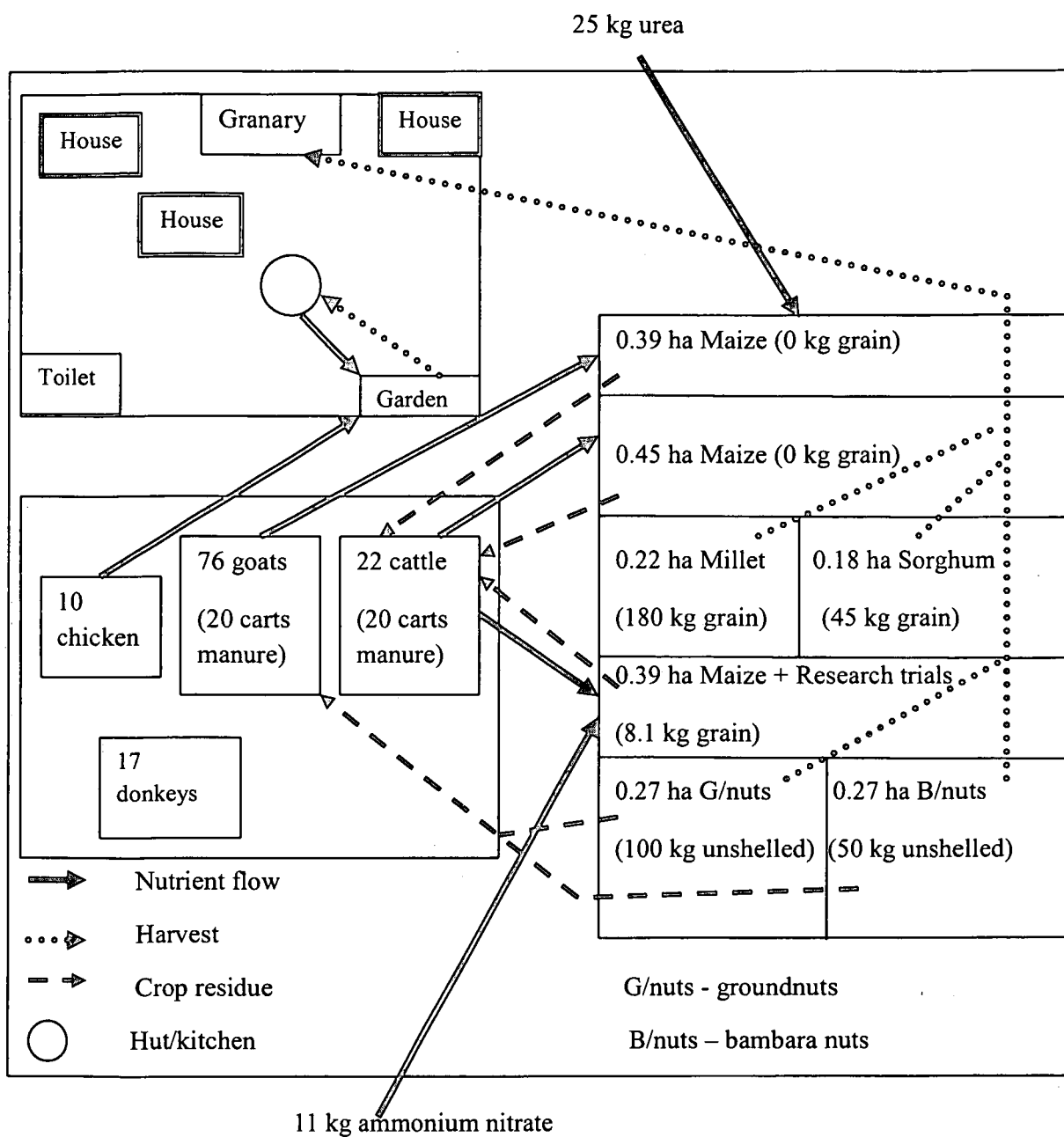


Figure 6.1. Resource flow map for Mr. John Ncube of Gwanda district. The map represents flow of resources at a farm that interacted with researchers for three cropping seasons

The farm of the 76 year old, Mrs. Malotha is located in Humbane village of ward 17 in Gwanda district (Fig. 6.2). The map summarizes allocation of agricultural resources during 2007/08 growing season. The household of Mrs. Malotha comprises three adults and two primary school going children. One of the three adult family members is working in Botswana and comes home occasionally during the course of the year. The farm size for the Malotha family is about three and half hectares. Despite having 16 goats Mrs. Malotha emphatically stated that she does not use livestock manure and inorganic fertilizers because they burn her crops. This is a widely held view by most smallholder farmers in semi-arid areas of Zimbabwe (Chibudu *et al.*, 2001; Mapfumo and Giller, 2001; Twomlow *et al.*, 2008b). Mrs. Malotha said she once used topdressing fertilizer that was donated by government in the 1980s and her sorghum crop wilted. She attributed the poor performance of that sorghum crop to the fertilizer that she had applied. During the 2007/08 growing season no soil fertility amendment was used at the farm and all maize residues were stored for feeding goats. The farming system at Malotha farm could lead to nutrient mining and consequently reduced soil productivity and crop yields. Continuous nutrient depletion without replacement through organic and inorganic sources has been observed on smallholder farms in sub-Saharan Africa (Smaling *et al.*, 1997). Legume stover was grazed *in situ* by her animals and those from the neighbourhood. The 300 kg of sorghum harvested was consumed at the farm. Both farms relied on family members for all agricultural activities during 2007/08 growing season.

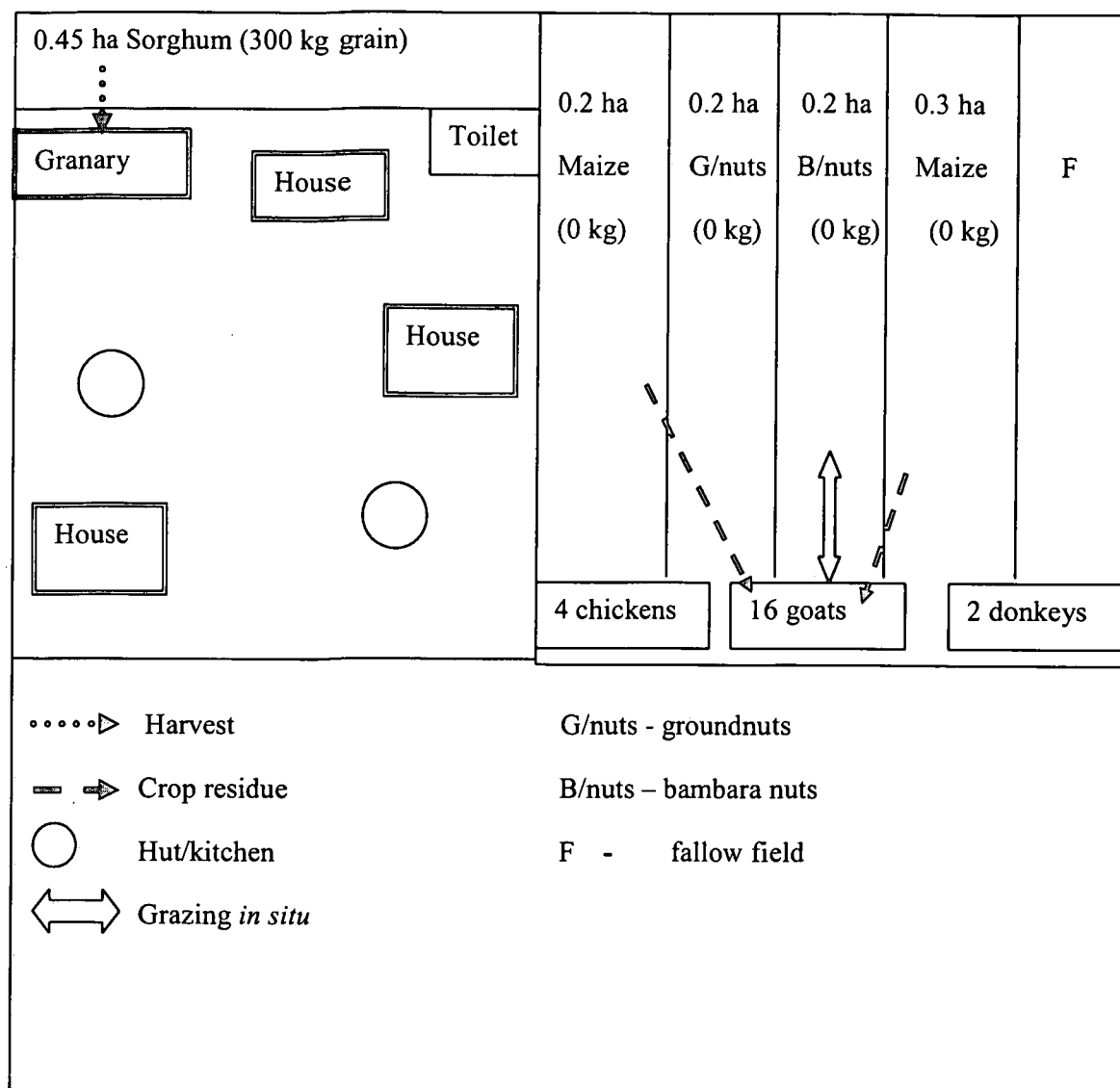


Figure 6.2. Resource flow map for Mrs. Malotha of Humbane village, Gwanda district. The map represents flow of resources at a farm that had no interaction with researchers from 2005/06 to 2007/08 seasons

6.4.1.3 Sources of seed for all farms

Pearl millet was only grown by farmers in Gwanda district and they planted retained seed in 2005/06, 2006/07 and 2007/08 growing seasons. The majority (58 %) of the farmers planted

retained sorghum seed while the bulk of maize seed (40 %) came from ICRISAT for the research field (Fig. 6.3 and 6.4). The Grain Marketing Board (GMB) through its ‘Operation Maguta/Inala’ program is also emerging as a major source of cereal seed (14-15 %) in both Gwanda and Insiza districts. The ‘Operation Maguta/Inala’ was officially launched in November 2005 to assist smallholder farmers with farming inputs. Farmers who were not hosting research trials planted seed received from various NGOs namely World Vision, Practical Action and Organization of Rural Associations for Progress (ORAP). All legume seed planted in the three seasons was either seed retained on the farm or was bought from neighbours with quantities ranging from 0.25 to two kg. Seed availability is a great constraint to farmers in Gwanda and Insiza districts, and this observation is consistent with results obtained from both sub-humid and semi-arid districts by other researchers (Ncube, 2007). NGOs have assumed a major role in providing both cereal and legume seed through a variety of Agricultural Relief programs in recent years. Access to good quality seed of appropriate crop types is crucial to increase production on smallholder farms.

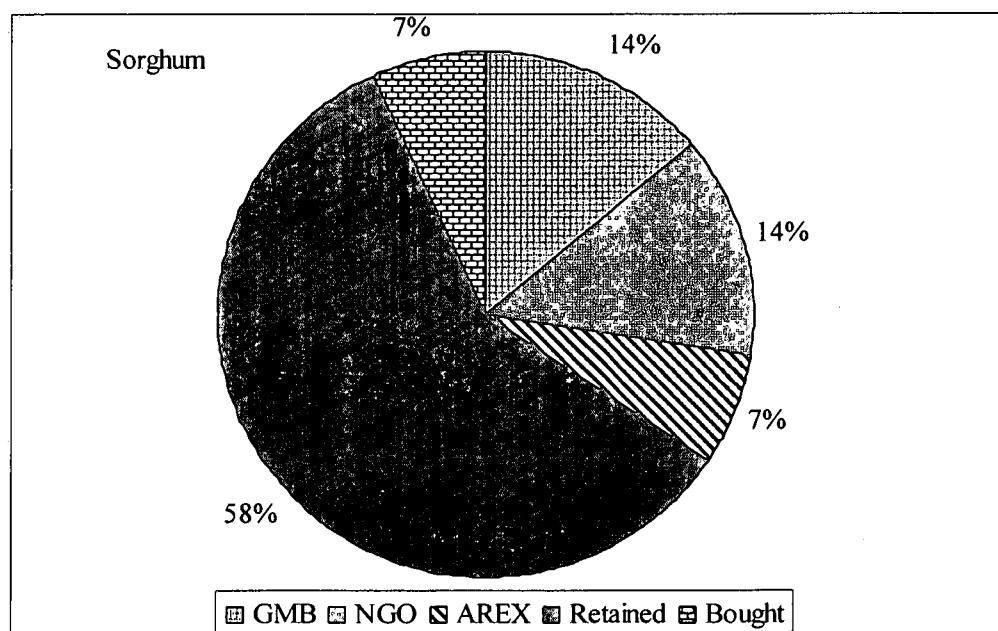


Figure 6.3. Average sources of sorghum seed planted by 14 households in 2005/06, 2006/07 and 2007/08 seasons in ward 1 of Insiza and ward 17 of Gwanda district

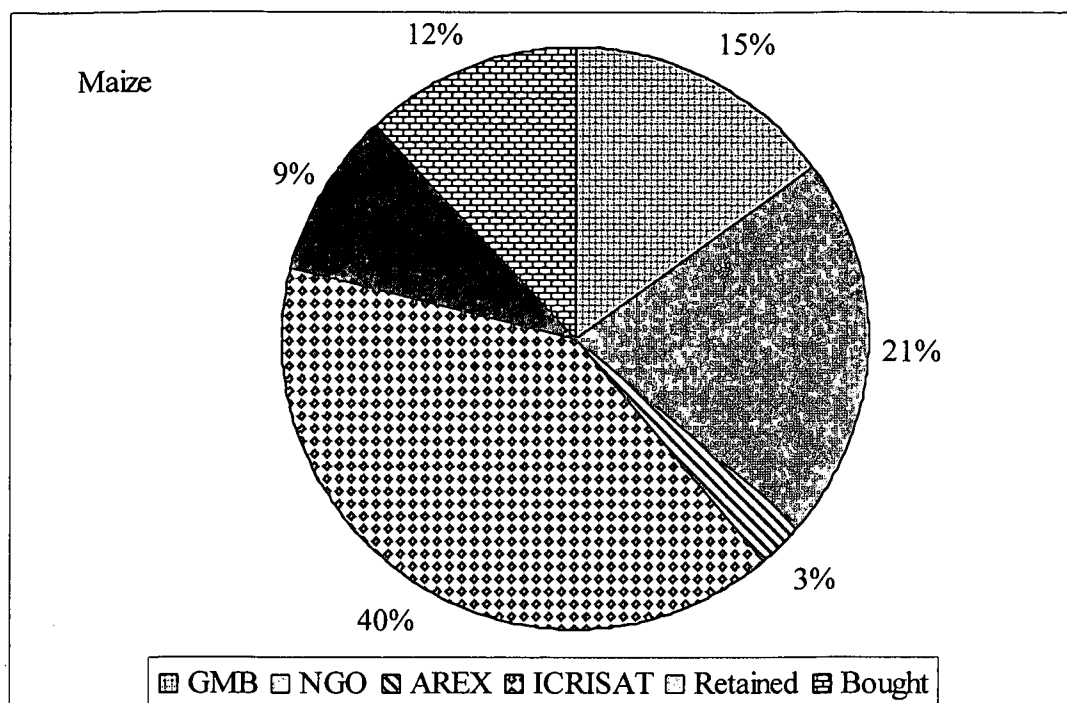


Figure 6.4. Average sources of maize seed planted by 14 households in 2005/06, 2006/07 and 2007/08 seasons in ward 1 of Insiza and ward 17 of Gwanda district

6.5 What the farmers said

6.5.1 Land preparation

Crop production in Gwanda and Insiza districts is done at a subsistence level. Tables 6.2 and 6.3 summarize agricultural activities and time when they were carried out on the conventionally ploughed farmer's fields and research plots during 2005/06 and 2007/08 growing seasons. On the research plots, single conventional ploughing was carried out during November and December depending on the onset of the rains. The first ploughing in double ploughing tillage system (for the research plots) was done between August and October each year (Table 6.4) with farmers in Insiza district generally carrying out the operation earlier than those in Gwanda district. All farmers broadcast cattle manure before ploughing in both single and double ploughing tillage systems. Ripping was done in October and November (Table 6.5) while digging of planting

basins was carried out during September and October each year (Table 6.6). Manure was banded along the ripped furrow in the ripper system and applied soon after ripping. In the basin system manure was placed in each planting basin soon after the basins were opened (Table 6.6).

Table 6.2. Cropping calendar for the farmer practice fields in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Land preparation												
Planting												
First weeding												
Second weeding												
Topdressing												
Harvesting												

Table 6.3. Cropping calendar for the single conventional ploughing in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Land preparation												
Planting												
First weeding												
Second weeding												
Topdressing												
Harvesting												

Table 6.4. Cropping calendar for the double conventional ploughing in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons

Activity	J	A	S	O	N	D	J	F	M	A	M	J
First ploughing												
Second ploughing												
Planting												
First weeding												
Second weeding												
Topdressing												
Harvesting												

Table 6.5. Cropping calendar for the ripper system in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Land preparation												
Planting												
First weeding												
Second weeding												
Third weeding												
Topdressing												
Harvesting												

Table 6.6. Cropping calendar for the basin system in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons

Activity	J	A	S	O	N	D	J	F	M	A	M	J
Land preparation												
Planting												
First weeding												
Second weeding												
Third weeding												
Topdressing												
Harvesting												

6.5.2 Planting

Planting period for all tillage systems stretches from November to December and is also being extended into January by farmers under their traditional methods. Planting date relies on the onset of the effective rains which normally vary from season to season. Planting basins and ripper tillage systems were planted first during the three seasons of experimentation. The earliest planting in these systems was done during the first week of November whilst the last planting date recorded between 2005 and 2008 was 29 December. Thus planting basin and ripper tillage systems allow timely land preparation and planting (Nyagumbo, 2007; Twomlow and Hove, 2007). Farmers both with or without draught power can make effective use of the planting rains in November-December if land is already prepared for planting. Maize planting in farmers' fields, single and double conventional ploughing plots was done in December across all the seasons. Dry planting of pearl millet on other fields of some farms was done in October with

sorghum and maize being planted between November and December. Cropping calendars presented by Twomlow *et al.* (2006b) showed that planting on smallholder farms in semi-arid areas can begin in October while harvesting stretches up to May. Planting of maize was done in furrows opened by donkey/ox drawn plough. Although smallholder farmers normally plough-plant in the third furrow (Chapter 5; Twomlow *et al.*, 2006b) farmers and researchers agreed at the beginning of the trials that third furrow plough-planting will not be done on the research plots so maize seed was planted in furrows that were opened by a donkey drawn plough.

6.5.3 Weed management

In the farmers' fields weeding was done by donkey-drawn cultivator first, followed by hand weeding. In the four experimental tillage systems weeding was done by hand hoeing throughout the three seasons of study. In the planting basin and ripper systems first weeding was done soon after planting between end of November and early December (Tables 6.5 and 6.6). The second weeding was done in the first two weeks of January on farmer practice, single and double ploughing treatments (Tables 6.2, 6.3 and 6.4). In 2005/06 growing season farmers reported high weed pressure and the majority of them weeded for the fourth time in March 2006. Weed management is one of the major challenges to adoption of conservation agriculture systems (Nyagumbo, 2007). Frequency of weeding depends on the rainfall pattern for each season with single weeding common in a dry cropping season and three or more weeding in wet seasons (Van der Meer, 2000). In the single and double ploughing systems (Tables 6.3 and 6.4), and farmer practice field (Table 6.2) weeding started in January and second weeding was done in February. None of the participants practiced winter weeding in the planting basin and ripper tillage systems. The reasons highlighted by the farmers were (i) there will be no crop in field; (ii)

there are other activities that are more important than weeding during winter period; and (iii) it is 'socially strange' to weed in winter when there are no crops growing '*neighbours will laugh at you*'.

6.5.4 Crop establishment

Farmers observed that the best maize crop establishment was in the basin system regardless of rainfall distribution during the November-December period. Maize crop establishment in the ripper system was ranked second with single and double conventional ploughing having similar plant stands despite different rainfall patterns observed during 2005/06, 2006/07 and 2007/08 growing seasons.

6.5.5 Labour requirements

Based on a plot size of 50 m x 50 m (0.25 ha) farmers estimated the labour requirements for land preparation and weeding for the different tillage systems (Tables 6.7 and 6.8). Planting basin system had the highest labour demand across all households during 2005/06, 2006/07 and 2007/08 growing seasons. The farmers unanimously agreed that reopening planting basins was generally easier than establishing them for the first time. Participants in the group discussions described the soil as 'softer' when they were reopening planting basins at the beginning of 2007/08 growing season. It has been observed in other districts of Zimbabwe that once established, reopening planting basins in the same position in successive years becomes easier (Twomlow and Hove, 2006). Ripping to a depth of 0.15-0.18 m at 0.9 m inter-row spacing required the least number of people and took the shortest time.

Table 6.7. Farmer assessment of labour demands for land preparation on a 0.25 ha plot of different tillage systems tested on their farms averaged for three growing seasons

Tillage system	Number of people	Time taken (days or hours)
Plough-planting	3	3 hours
Double conventional ploughing	2 (3)	3 (3) hours
Ripping	2	1 hour
Planting basins (first time)	10	3 days
Planting basins (reopening)	7	3 days

Figures in brackets stand for number of people and time taken for the second conventional ploughing

The highest labour demands for weeding were in the ripper and planting basin tillage systems regardless of the rainfall pattern (Table 6.8). Some farmers resorted to weeding using ox/donkey drawn cultivator on their fields especially during 2005/06 season. Hand weeding or ox-drawn cultivation followed by hand hoeing are common practices for weed control (Chapter 5). Frequency of weeding depends on the rainfall pattern for each season with single weeding common in a dry cropping season and three or more weeding in a wet year (Van der Meer, 2000). Data available from research studies conducted in Zimbabwe clearly show that timely and effective weed control improves soil water conservation and crop yields (Van der Meer, 2000). Studies conducted by Shumba *et al.* (1992) at Matopos and Makoholi research stations also showed that early weeding resulted in 40% more maize grain than the farmers' practice which was used as a control.

Table 6.8. Farmer assessment of weeding methods, frequency and labour demands during seasons with different rainfall pattern in Gwanda and Insiza districts

Tillage system	Weeding method		Weeding frequency		Labour requirement (mandays)	
	Below normal rainfall	Above normal rainfall	Below normal rainfall	Above normal rainfall	Below normal rainfall	Above normal rainfall
Plough plant	Animal drawn cultivator followed by hand hoeing	Animal drawn cultivator followed by hand hoeing	1	2 - 3	4	5
Single ploughing	Animal drawn cultivator followed by hand hoeing	Animal drawn cultivator followed by hand hoeing	1	2 - 3	4	5
Double ploughing	Animal drawn cultivator followed by hand hoeing	Animal drawn cultivator followed by hand hoeing	1	2 - 3	4	5
Ripper	Hand hoeing	Hand hoeing and hand pulling	2	3 - 4	5	8
Planting basins	Hand hoeing	Hand hoeing and hand pulling	2	3 - 4	5	8

6.5.6 Soil fertility management

The majority of participants in focus group discussions in Gwanda district did not use livestock manure or inorganic fertilizers in their farming system. The farmers believe that inorganic fertilizers and manure burn their crops, while others within the same group of farmers were of a strong opinion that their soils contain enough plant nutrients to sustain crop production. This confirmed earlier survey reports by Ahmed *et al.* (1997) that revealed low fertilizer usage by smallholder farmers in semi-arid southern Zimbabwe. Given the results from resource flow mapping and focus group discussions nutrient mining from agricultural fields could be rampant

in Gwanda district. Smallholder farmers in Insiza district had been using both inorganic fertilizers and livestock manure before researchers arrived in their area. Compound D fertilizer is applied at planting by dribbling along planting furrows or placed in each planting hole next to the seed. Livestock manure is applied in September/October as small heaps and broadcast later at ploughing after effective planting rains. Quantities of manure applied vary from 4 to 6 tha^{-1} . Although the national extension service recommends 8 tha^{-1} for semi-arid districts (Mapfumo and Giller, 2001), studies conducted by Ncube *et al.* (2007) in Tsholotsho district showed that 3 to 6 tha^{-1} supplemented with low rates of nitrogen fertilizer significantly increase cereal yields. Topdressing fertilizer in Insiza district is applied to maize from the end of January through to February. Some farmers use teaspoons for measuring quantities of fertilizer (either basal or topdressing type) to apply per planting station while others use tips of their fingers. Farmers in the focus group discussions normally applied 25 kg of either compound D or ammonium nitrate received from NGOs to a 50 m x 50 m plot of maize, sorghum or pearl millet. This is the equivalent of 200 kgha^{-1} of either the compound D or topdressing fertilizer, which is the blanket recommendation for smallholder farming systems of southern Zimbabwe from AGRITEX.

6.5.7 Soil water conservation and the effect of dry spells on a maize crop

Participants were asked to share their observations on the effect of dry spells on the maize crop growing under single and double ploughing, planting basins, ripper and farmer practice fields. The ripper system was overwhelmingly voted as the tillage practice most affected by dry spells. Only one farmer from Gwanda district, Mr. John Ncube, observed the least water stressed maize crop in the ripper system during dry spells over the three seasons of experimentation. During 2006/07 which was a drought year, farmers observed maize plants wilting first in the ripper

plots. The double ploughing and planting basin tillage systems were nominated by the farmers as the best systems that managed to extend the soil water availability to crops during dry periods. The impact of dry spells on maize grown under single conventional ploughing was less than that on ripper tillage system. The fact that there was lower soil water availability under the ripper system compared with double ploughing and planting basin systems was confirmed by field measurements taken during 2006/07 growing season (Mupangwa *et al.*, 2008; Chapter 7).

6.5.8 Crop yield assessment

Farmers used maize yields achieved in 2005/06, 2006/07 and 2007/08 growing seasons, to rank the four tillage systems and results are summarized in Figure 6.7. The double ploughing tillage system was ranked the highest yielding system by 46 % of farmers in the focus group discussions. Planting basin system was ranked second while all participants observed that the single ploughing tillage system was the lowest yielding across three seasons (compare yields in Chapter 7).

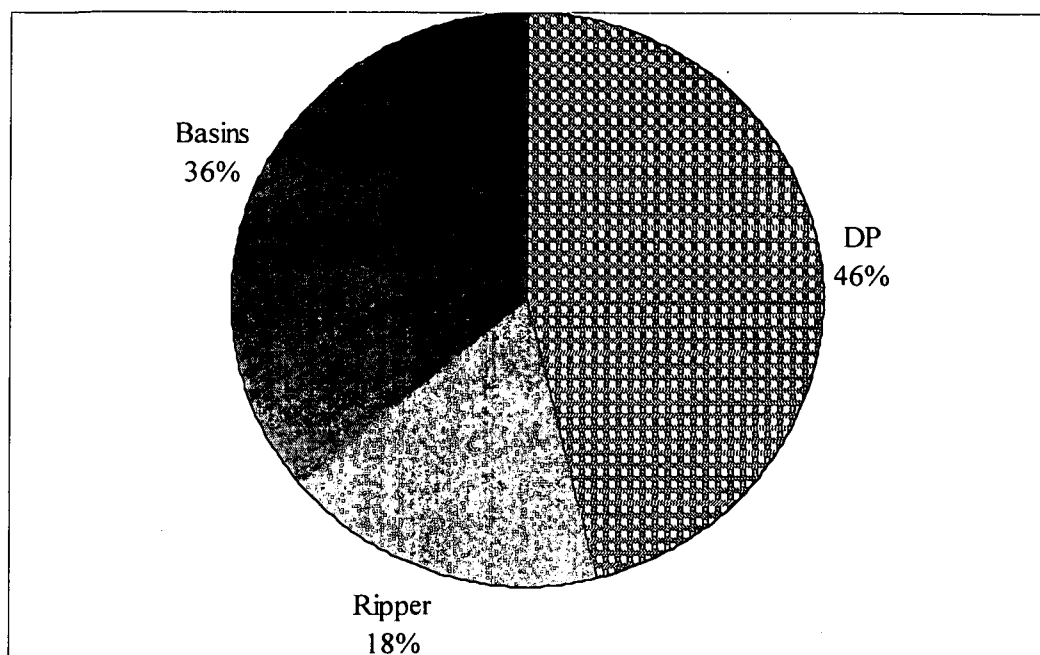


Figure 6.5. Farmer ranking of basin, double ploughing (DP) and ripper tillage systems tested on their fields for three growing seasons in Gwanda and Insiza districts. Ranking was based on maize grain yields achieved over three growing seasons

6.5.9 Pests and diseases

The pests observed across the three seasons of experimentation are shown in Table 6.9. Mice were a menace in planting basins particularly during 2006/07 season when there was a drought. This was also reported in other semi-arid districts where planting basins were being promoted during the same season. The armored cricket attacked the maize grain at milk dough stage and the attack was more severe in 2005/06 and 2007/08 seasons. No diseases were observed on the maize crop in the on-farm research plots during the three growing seasons.

Table 6.9. Pest species in different tillage system affected as observed by farmers in Gwanda and Insiza districts during 2005/06, 2006/07 and 2007/08 growing seasons

Pest	Tillage system	Crop growth stage affected
Green grasshopper	All	Vegetative and reproductive
Mice	Basins	Between planting and crop emergence
Cutworms	All	Soon after crop emergence
Birds	All	Between planting and crop emergence
Termites	All	Harvest maturity
Armored cricket	All	Milk dough

6.5.10 Preferred tillage system and crops to be grown

The participants chose tillage system(s) that they would prefer to continue using in future without the researchers. The choice of tillage systems revealed some sharp differences between husbands and wives participating in focus group discussions. The female farmers were equally divided between selecting to continue with double ploughing and planting basin tillage systems (Fig. 6.6). Female farmers who preferred planting basins gave the following reasons for their choice: (a) crop establishment is better in planting basins and if the rainfall season is good there are better chances of high yields and (b) manure and topdressing fertilizer can cover a larger area of cropped fields when maize is grown in planting basins as it is placed only in each basin. However, the female farmers highlighted the challenge of the high labour needed to dig planting basins. They suggested working in groups, as the best way forward, during land preparation stage.

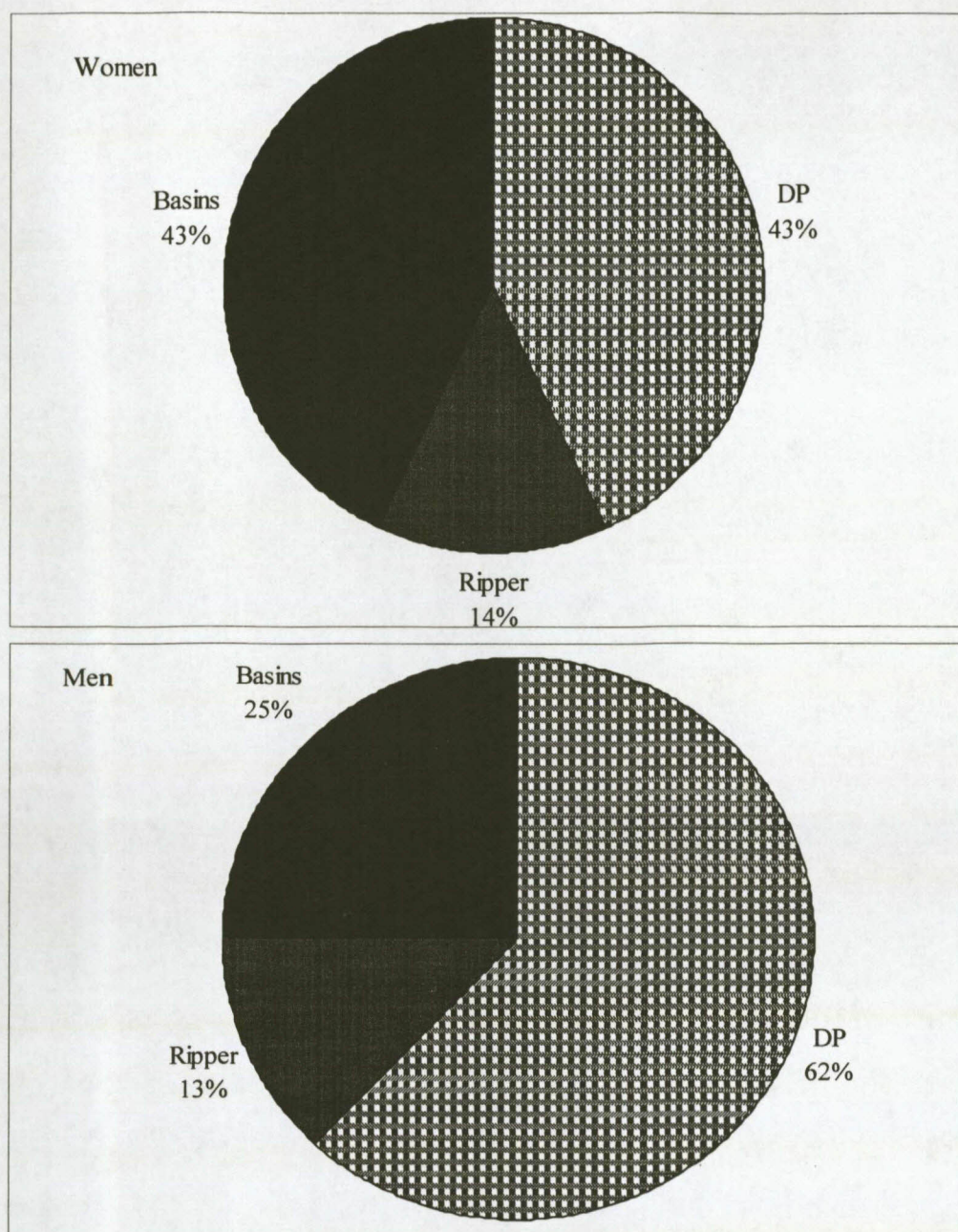


Figure 6.6. Tillage systems chosen for adoption by female and male farmers during focus group discussions in Gwanda and Insiza districts

The majority (62 %) of male farmers strongly voiced their concern over labour requirements for the basin system and they selected the double ploughing system. The opinion of male farmers on using of planting basins can be summarized by this statement which came from a farmer who

worked with researchers for three seasons '*Ukhulima ngamagodi hukhuhambisa umuntu ejele leKhami*' which literally means 'farming using planting basins is like taking someone to Khami prison'. Male farmers gave the following reasons for choosing the double ploughing system: (a) maize plants in double ploughed plots showed less soil water stress during dry spells and highest grain yields were obtained from the double ploughing system; (b) weeding was not a problem even in growing seasons with above-normal rainfall pattern such as 2005/06 and (c) land preparation is done using ox/donkey drawn plough. However, all the farmers proposed growing pearl millet, sorghum, traditional spreading cowpea varieties and groundnuts under the ripper or basin tillage systems.

6.5.11 Technical and material support

The farmers who participated in the focus group discussions identified sources of farming advice that they had received before ICRISAT researchers came to the area and during the period of hosting research trials. They also highlighted the support they had received from each organization and the support expected in future (Table 6.10). Ranking of organisations based on support rendered to the farmers was done based on a scale of one to five with the former being a lot of support and the latter representing least support. The AGRITEX was given a low rank in both Gwanda and Insiza, as they are facing many challenges ranging from lack of financial and material resources to high staff turnover. The high staff turnover has a negative impact on agricultural development programmes such as conservation agriculture (CA) (Hove, 2006). Practical Action was ranked highly in Gwanda district because farmers appreciated the rainwater harvesting program that brought dead level contours, tools such as wheelbarrows and shovels, and food rations during the construction of the contours.

Table 6.10. Farmer ranking of organisations working in Gwanda and Insiza, and support rendered and expected by farmers in Gwanda and Insiza districts. (1 = lot of support; 5 = little support)

Organisation	Rank	Support provided	Future support required
AGRITEX	4 (Gwanda and Insiza)	◦ Pegging contour ridges ◦ Farmer training in crop production	◦ Training on fertilizer and manure use ◦ Crop pests and disease control ◦ Animal pests and disease control ◦ Striga control ◦ Frequent visits to farmers' fields
Practical Action	1 (Gwanda)	◦ Setting up dead level contours and infiltration pits ◦ Food and tools for dead level contours' program	◦ Setting up storage tanks along dead level contours
World Vision	2 (Insiza) 4 (Gwanda)	◦ Seed and fertilizer ◦ CA training	◦ Seed and fertilizer ◦ Training on fertilizer and manure use ◦ Crop pests and disease control
ICRISAT	1 (Insiza) 2 (Gwanda)	◦ CA training ◦ Extension materials e.g. planting basins and ripper calendars ◦ Frequent visits to farmers' fields	◦ Extension materials ◦ Modify the ripper tine so that it creates bigger furrows
Grain Marketing Board	3 (Gwanda and Insiza)	◦ Seed and fertilizer	◦ Seed and fertilizer
Lutheran Development Services	5 (Gwanda)	◦ Seed and fertilizer for nutrition gardens	◦ Seed and fertilizer for nutrition gardens ◦ Training on vegetable production

6.6 Conclusion

All households who participated in the resource flow mapping exercise own a piece of land where crop production is done at a subsistence level. Each household owns at least one of the following animal species: free range chickens, goats, donkeys and cattle. Each participating

household had access to a plough and hand hoes, and an average of three family members provide labour for agricultural activities.

The common agricultural resources used by better resourced households in Gwanda and Insiza districts are seed, manure and inorganic fertilizer. The low resourced households particularly in Gwanda district (NR V) do not use any soil fertility amendments regardless of the in-season rainfall pattern. This implies that low resourced households miss out on opportunities of better crop yields when rainfall conditions are favourable as was the case in the 2005/06 growing season. The households that do not apply organic and inorganic soil fertility amendments still believe that manure and fertilizer burn their crops and should not be used in southern Zimbabwe. These farmers require training on manure and fertilizer application quantities and field days (green and brown shows) should be organized at the fields of their colleagues who are applying soil fertility amendments. Research and extension agents have some work to do to demystify such perceptions as there are dangers of serious nutrient mining and hence soil degradation in semi-arid smallholder cropping systems. Technologies such as microdosing that have proved beneficial in other semi-arid districts should be promoted more widely to reach out areas such as the southern parts of Gwanda district. The households who are using soil fertility amendments have observed the benefits of addressing soil fertility and now know the quantities of manure and fertilizer to apply. The accessibility of agricultural inputs such as inorganic fertilizers needs to be improved for the benefit of farmers such as Mr. John Ncube.

During the evaluation exercise, farmers did not just consider maize yields, they also took into consideration auxillary benefits such as good crop establishment, quantities of inputs used, area

covered by a given quantity of inputs and labour demands. Farmers appreciated that farming using planting basins and ripper systems allows timely planting because land is prepared well before the onset of the rains. This therefore reduces demand on limited family labour during the planting period. The focus group discussions showed that husbands and wives, coming from the same household, differed in their choice of technologies to be adopted on their farms. This demonstrates how individual farmers, viewed by change agents as all vulnerable, differ on what they see as opportunities and constraints of different soil and fertility management technologies.

A concerted effort by all service providers in Insiza and Gwanda districts should be made to reach out to farmers with proven technologies. It has been seen that some of the technology transfer methods have been successful with specific farmers. An investigation into those methods should be made so as to use them again. An alternative is to use farmer to farmer transfer by promoting groups and visits to each other's farms so as to enable learning and capacity building and still transfer the technologies.

CHAPTER 7

Integrated Tillage and Nitrogen Management for Improved Soil and Water Productivity on Smallholder Farms in Semi-Arid Zimbabwe

7.1 Introduction

Smallholder agriculture in semi-arid areas is facing many challenges including low, erratic and highly variable rainfall between and within seasons (Rockström *et al.*, 2002; Twomlow *et al.*, 2006b). Droughts and intra-seasonal dry spells are common in semi-arid southern Zimbabwe. To reduce the impact of the frequently occurring droughts and dry spells on smallholder cropping systems, soil water management technologies have been developed (Vogel, 1992; Nyamudeza, 1993; Nyakatawa *et al.*, 1996; Twomlow and Bruneau, 2000). The findings from these studies have indicated that the period of soil water availability to crops can be prolonged even on granitic sandy soils.

The low crop yields achieved from the smallholder cropping systems are often *blamed* on the rainfall pattern during the growing season. However, when rainfall is adequate crop production is limited by the low fertility status of the predominantly granitic sandy soils in the smallholder sector. There is continued nutrient off take in harvested crops without replenishment through use of organic and inorganic nutrient sources (Stocking, 2003). The major chemical and physical constraints with the sandy soils in smallholder farming system include the inherent low levels of organic matter, nitrogen and phosphorus, and the poor soil structure (Grant, 1981; Nyamangara and Mpofu, 1996; Twomlow *et al.*, 2006b). Studies conducted in the northern

(Mtambanengwe and Mapfumo, 2005) and southern (Ncube *et al.*, 2007) parts of Zimbabwe demonstrated that livestock manure is a key resource for improving productivity of the sandy soils on the smallholder farms. Crop yields in the smallholder farming systems can be increased substantially by supplementing manure with nitrogen fertilizer (Mubonderi, 1999; Nhamo, 2003; Ncube *et al.*, 2007). The wide scale promotion of the use of low rates of nitrogen fertilizer (10 kgNha^{-1}) in semi-arid smallholder cropping systems demonstrated that cereal yields can be increased by 30 to 100 % in the conventional tillage system (Twomlow *et al.*, 2008b).

Deep winter ploughing is a technique which has been recommended by the government's department of agriculture research and extension (Mupangwa *et al.*, 2006). The technique involves ploughing to a depth of 0.2 – 0.23 m soon after harvesting. However, smallholder farmers only plough to a depth of 0.1 – 0.15 m resulting in the formation of a hardpan within the soil profile (Tsimba *et al.*, 1996). The plough pan restricts root penetration and rainwater penetration to deeper soil layers. Crops grown under shallow ploughing cannot withstand extended periods of soil water stress during mid-season dry spells.

The planting basin and ripper tillage techniques are being promoted on smallholder farms in semi-arid Zimbabwe (Mupangwa *et al.*, 2006). These tillage systems combine water with nutrient management practices. Planting basins are targeted at households that have little or no access to animal draught power (Twomlow and Hove, 2006) while the ripper tillage system was designed for households with some draught power. The two tillage systems emphasize the spreading of labour requirement throughout the year, the precise application of nutrients and timeliness of

management operations. Land preparation in the planting basin and ripper systems starts in October (Chapter 3). Rain water collects into the basins or ripper furrows during the early season rainfall events (October and November) allowing those parts of the field to be wetter than the rest of field, even with little rain. Studies conducted in Botswana and Zimbabwe have demonstrated that double spring ploughing can increase crop yields in a wide range of soil types under semi-arid conditions (Twomlow and Bruneau, 2000). This chapter presents results obtained from three seasons of participatory on-farm experimentation in Insiza NR IV and Gwanda NR V districts of semi-arid Mzingwane catchment of southern Zimbabwe.

7.2 Objectives

This study was designed to use on-farm trials in farmers' fields

- (1) to quantify soil water content under single and double conventional ploughing, ripping and planting basin tillage systems;
- (2) to quantify runoff water losses from single and double conventional ploughing, ripper and planting basin tillage systems;
- (3) to determine effect of the four tillage systems and nitrogen fertilizer on maize crop performance; and
- (4) to determine water use and agronomic nitrogen use efficiencies under the four tillage systems.

7.3 Materials and Methods

7.3.1 Experimental design and layout

The experimental design was split plot with tillage method as the main plot factor, nitrogen fertilizer level as the sub-plot and each farm was considered as a replicate

with districts being the blocks in the study. The four tillage treatments were planting basins (Basins), tine ripping (Ripper), single (CP) and double (DP) ploughing. The three nitrogen rates were 0, 10 and 20 kgNha⁻¹ applied as ammonium nitrate (34.5% N). Each tillage main plot measured 20 m x 10 m in 2005/06 season and 30 m x 10 m in 2006/07 and 2007/08 seasons. In the first season only 0 and 10 kgNha⁻¹ were used while a third rate of 20 kgNha⁻¹ was introduced in the second and third growing seasons.

In 2005/06 season plots were pegged out in October 2005 before all tillage operations commenced. In 2006/07 season new plots were pegged out in the same fields because main plot size had increased from 20 m x 10 m to 30 m x 10 m. The plots established in 2006/07 season were maintained for 2007/08 growing season. Planting basins were dug at 0.9 m x 0.6 m spacing using a hand hoe and each basin measured 0.15 m (length) x 0.15 m (width) x 0.15 m (depth). Rip lines were opened at 0.9 m inter-row spacing using a ZimPlow ripper tine attached to the beam of an ox or donkey-drawn mouldboard plough (Plate 3.4c, Chapter 3). The first conventional ploughing for the double ploughing treatment was carried out in September/October each year. The second ploughing was done at the same time as the single conventional ploughing treatment soon after the first effective rain (20 to 30 mm) in November/December each year using a donkey-drawn mouldboard plough. Shallow planting furrows were opened by donkey-drawn plough in the single and double ploughing treatments (open-plough furrow planting).

7.3.2 Experimental management

Planting on all farms occurred between late November and December depending on the start of the rainy season. A short season hybrid maize variety, SC403, was planted at all farms during each of the three cropping seasons. Three kernels were planted per basin in the basin tillage system. Two kernels were planted per station at 0.3 m in-row spacing in the ripping, single and double conventional tillage treatments. Plants were thinned to two per basin in planting basin and one plant per station in the ripping, single and double conventional tillage treatments two weeks after planting.

Cattle manure was applied each year at a rate of 3 tha^{-1} in all plots under planting basins, ripper, single and double ploughing tillage treatments as basal soil fertility amendment. Manure was placed in the planting basins and dribbled along the ripline. In the single and double ploughing tillage systems manure was broadcast just before the ploughing operation. The annual 3 tha^{-1} application rate for manure is the current recommendation under the Protracted Relief Program (PRP) for the smallholder farming sector where conservation agriculture is being promoted. Ammonium nitrate was spot applied on top of the soil between January and February and each tillage main plot was subdivided into two during the first season and into three subplots during the 2006/07 and 2007/08 seasons. The 10 m x 10 m subplots were for accommodating the N treatments. Weeds were controlled by hand hoe at all farms across all three seasons.

7.3.3 Data collection

7.3.3.1 Soil analyses

All soil properties were determined using procedures outlined by Anderson and Ingram (1993). Soil pH was determined by the water method in a 2:5 soil:water ratio. Soil organic carbon, and total N and P were determined by the Sommers and Kjeldahl methods (Anderson and Ingram, 1993). Available P was extracted by the bi-carbonate procedure and determined calorimetrically. Total N and P in plant tissue were also determined using the Kjeldahl procedure. Soil texture was determined by the hydrometer method as outlined by Anderson and Ingram (1993).

7.3.3.2 Soil water content and daily rainfall

During the first season (2005/06) soil water was measured monthly by the gravimetric method at five farms namely Moyo and Mpofu in Insiza district, and J. Ncube, Sibanda and Siziba in Gwanda district. Soil samples were collected at 0.15 m depth intervals up to 0.6 m by steel cores measuring 0.03 m internal diameter by 0.95 m length. Soil samples were oven dried at 105°C for 48 hours before determining gravimetric water content. Volumetric water content was calculated using bulk density and gravimetric water content of each soil layer (Anderson and Ingram, 1993). During the 2006/07 season, soil water was measured at Mpofu and Nyathi farms in Insiza district and, J. Ncube, Sibanda and Siziba farms in Gwanda. In the 2007/08 season, soil water was measured at Mpofu, N. Ncube and Nkomo farms in ward 1 of Insiza district. In Gwanda district soil water was measured at J. Ncube, Sibanda and Siziba farms. During the 2006/07 and 2007/08 seasons volumetric soil water content was measured using a capacitance probe (*microgopher sensor type*). Depth of access tubes varied between 0.6 and 0.8 m and three access tubes were installed per tillage

main plot. Depth of access tubes was restricted by presence of a lateritic layer in the profile especially at experimental sites in Insiza district. Soil water was measured fortnightly at 0.1 m depth increments during 2006/07 and 2007/08 seasons. Soil water content in millimetres was determined by multiplying volumetric water content by thickness of each layer from which soil water was measured. Each farmer was given an ordinary plastic raingauge for recording daily rainfall during the growing season.

7.3.3.3 Surface runoff

Runoff water collected from each tillage treatment plot was measured soon after each runoff-generating rainfall event. The height of water in the drum was measured by staff gauge graduated from 0 to 1.5 m. The drums were emptied after each rainfall event. Runoff water depth from each treatment was calculated by subtracting the volume of water contributed by the 10 m x 1.7 m triangular receiving surface from total water volume measured in the drum.

7.3.3.4 Maize plant stand and yield

In every season plant counts after thinning in each treatment were done two weeks after crop emergence. At harvest, grain and stover (above-ground biomass minus grain) yields were measured from 10 m x 10 m subplot for each tillage treatment. The weight of cobs and stover from the subplot of each tillage treatment was determined in the field before taking sub-samples for moisture correction. Grain and stover samples were dried at 60°C for 48 hours for moisture adjustment using formulae outlined in Equation 7.1. The maize shelling percentage was determined for each treatment for converting cob weight into grain weight. Grain weight was converted to a per hectare basis at 12.5% moisture content as final grain yield. The harvest index

was determined as a proportion of grain mass to total above-ground biomass mass (grain, cores and stover).

$$\text{Grain yield (kg ha}^{-1}\text{, @12.5\%)} = [(1 - MC)/(1 - 0.125)] \times FGW \quad \text{Equation 7.1}$$

Where MC = moisture content (%) measured in the cobs after drying for 48 hours at 60°C and FGW = grain weight at field moisture content (kg ha⁻¹).

7.3.3.5 Water and agronomic nitrogen use efficiencies

Water use efficiency (WUE) was calculated based on grain yield (kg ha⁻¹), changes in profile soil water (mm) and rainfall data (Fatondji *et al.*, 2006). Water use efficiency was calculated as:

$$WUE = Y / (P - (\Delta SW + D)) \quad \text{Equation 7.2}$$

where WUE = water use efficiency (kg ha⁻¹ mm⁻¹)

Y = grain yield (kg ha⁻¹)

P = precipitation (mm)

ΔSW = changes in soil water (mm)

D = drainage (mm) which was assumed to be negligible.

Agronomic nitrogen use efficiency (ANUE) was calculated based on grain yield and quantity of nitrogen applied (Fatondji *et al.*, 2006):

$$ANUE = \Delta Y / N \text{ applied} \quad \text{Equation 7.3}$$

where ΔY = difference in grain yield between N treated plot and zero N plot.

7.3.4 Statistical analysis

Statistical analysis was conducted on baseline soil characteristics, maize yield, soil water and runoff data. All analyses were performed with ANOVA procedure using Genstat Discovery Edition 3 (www.vsnl.co.uk). Baseline soil characteristics were analyzed using General Analysis of Variance with 'farmer' as the only factor in the model. Maize yield data were analyzed using a split plot design with tillage as main factor and nitrogen as sub-plot factor. The yield data were analysed for each season individually and later pooled and analysed across the three growing seasons. Soil water and runoff data were analyzed using the Unbalanced Treatment structure as the depths of access tubes for soil water measurements varied across the farms. Unbalanced design was applied in the analysis of runoff data because the four farms recorded different number of runoff events during 2006/07 and 2007/08 seasons. Least significant difference (Lsd) values calculated at 5 % significance level were used to compare the treatment means.

7.4 Results

7.4.1 Soil properties of soils at the experimental sites

Soil properties measured at the beginning of the experiment are given in Table 7.1. Significant ($P < 0.001$) differences in pH, organic carbon (O.C.) and total nitrogen (Tot. N) were observed across the farms. Total phosphorus content (Tot. P) of the soils used in the study also differed significantly ($P = 0.001$) across the farms. Siziba farm in Gwanda district had the highest pH and organic carbon content. Soil texture ranged from sand to loamy sand across the farms used during the three seasons of experimentation.

Table 7.1. Selected initial soil chemical and physical properties (0 – 0.6 m) at farms used from 2005/06 to 2007/08, Insiza and Gwanda districts

<i>District</i>	<i>Farmer</i>	<i>pH</i> (<i>water</i>)	<i>O.C.</i> (%)	<i>Tot. N</i> (%)	<i>Tot. P</i> (%)	<i>B.density</i> (<i>g/cm³</i>)	<i>Texture</i>
Insiza	Mguni	6.0	0.56	0.05	0.02	1.50	Sand
	Moyo	5.9	0.58	0.06	0.006	1.49	L. sand
	Mpofu	5.2	0.41	0.03	0.007	1.46	Sand
	Nkomo	5.6	0.36	0.02	0.006	1.50	Sand
	Mlalazi	5.5	0.36	0.02	0.009	1.52	Sand
	Ncube N	6.5	0.34	0.02	0.002	1.52	L. sand
	Nyathi	6.3	0.29	0.03	0.008	1.51	L. sand
Gwanda	Ncube J	5.3	0.33	0.03	0.009	1.49	Sand
	Sibanda	5.6	0.46	0.03	0.021	1.51	Sand
	Siziba	6.1	0.71	0.06	0.019	1.56	L. sand
	Lsd _{0.05}	0.53	0.18	0.033	0.007	0.020	
	CV (%)	7.3	29	40	43	1.1	

7.4.2 Seasonal rainfall and profile soil water regimes

7.4.2.1 2005/06 growing season

7.4.2.1.1. Insiza district

Insiza district which lies in NR IV received more rain than Gwanda district (NR V) during the three seasons the study was conducted. Rainfall was evenly distributed between November 2005 and February 2006 in ward 1 of Insiza district where experimental sites were located. The total seasonal rainfall was 541 and 535 mm for Mpofu and Moyo farms (Fig. 7.1). These seasonal rainfall totals were similar to the 74 year average for Filabusi which lies in Insiza district (Chapter 4). The growing season started on day 61 (30 November 2005) and ended on day 168 (17 March 2006) which is two weeks before the long term average at Filabusi. Thirty-one wet days were recorded across the two farms during 2005/06 growing season which is above the long term mean of 22 days but is not extreme (Chapter 4). The heaviest daily rainfall event of 53 mm was recorded on 11 February 2006 (day 134).

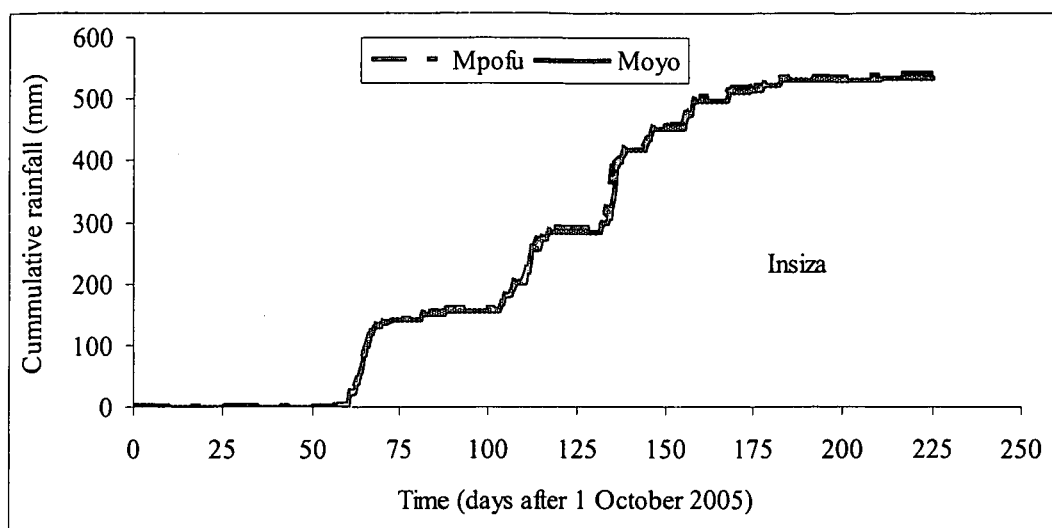


Figure 7.1. Cumulative rainfall distribution at Mpofu and Moyo farms of ward 1 in Insiza district during 2005/06 growing season

In the 2005/06 growing season basin and ripper tillage systems had higher ($P < 0.001$) profile water content than DP and CP systems on day 103 (11 January) when the first measurement was taken (Fig. 7.2). Profile water content ranged from 50 mm in the CP system to 86 mm recorded in the ripper and basin tillage systems. The DP system had 70 mm in the profile on the same day. Profile soil water content increased by 4, 11, 1 and 28 % in CP, DP, ripper and basin systems following 149 mm of rain that was accumulated between soil water measurements on days 125 (2 February) and 145 (22 February). The basin system had consistently more soil water in the soil profile from day 145 (22 February) until the last soil water measurement was taken on day 189 (7 April), suggesting better rainwater harvesting in the basin system.

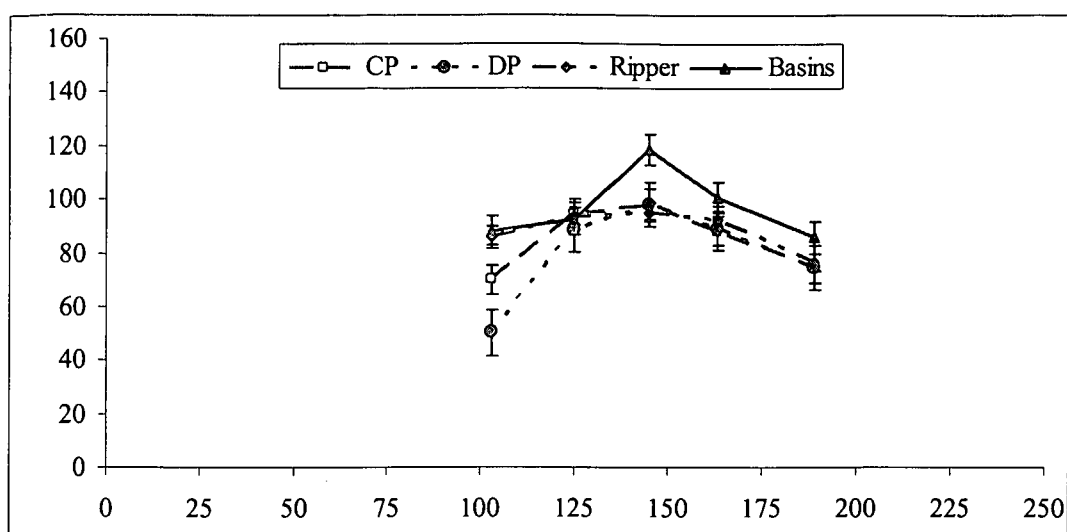


Figure 7.2. Profile soil water changes (0 – 0.50 m) averaged across two farms (Moyo and Mpofu) in ward 1 of Insiza district during 2005/06 growing season. Error bars represent standard errors of means

7.4.2.1.2 Gwanda district

Rainfall was evenly distributed between 28 November 2005 and 28 March 2006 across the three farms used in the 2005/06 growing season. The total seasonal rainfall was 286, 271 and 375 mm for Sibanda, Siziba and J. Ncube farms respectively (Fig. 7.3). The seasonal rainfall recorded at Sibanda and Siziba was 24 and 28 % less than the 50 year average rainfall for Beitbridge which is usually drier than Gwanda district (Chapter 4). The growing season started on day 70 (9 December) and ended on day 179 (28 March) with 22 wet days being recorded during the season. The length of the 2005/06 growing was 109 days and the highest daily rainfall event was 50 mm which was recorded on day 111 (19 January 2006) at Siziba farm. Two 19-day dry spells were recorded at Sibanda and Siziba farms from days 79 to 98 and 111 to 130.

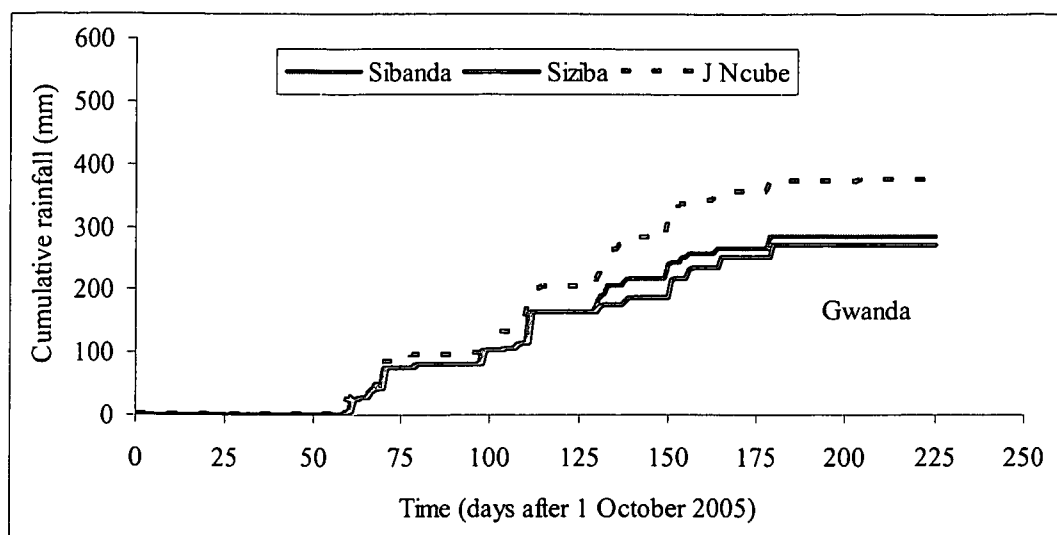


Figure 7.3. Cumulative rainfall distribution at Sibanda, Siziba and J. Ncube farms of ward 17 in Gwanda district during 2005/06 growing season

In the 2005/06 growing season basin tillage system had higher ($P < 0.001$) profile water content (78 mm) compared with 60 mm recorded in CP system, 63 mm in the DP and 54 mm in the ripper system when the first measurement was taken (Fig. 7.4). Profile soil water content increased by 18, 4 and 9 % in the DP, ripper and basin systems following 104 mm of rain that was accumulated between days 99 (7 January) and 136 (13 February). Profile soil water content decreased by 8 % in the conventional system between days 99 (7 January) and 136 (13 February). The tillage systems had similar ($P > 0.05$) profile water content from day 99 (7 January) until day 225 (13 May) when the last measurement was taken.

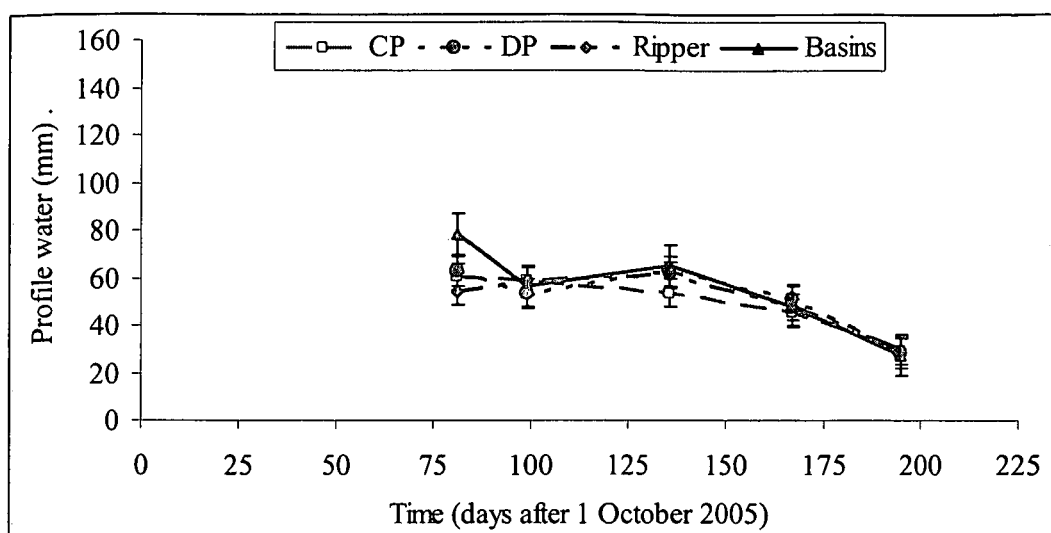


Figure 7.4. Profile soil water changes (0 – 0.60 m) averaged across three farms in ward 17 of Gwanda district during 2005/06 growing season. Error bars represent standard errors of means

7.4.2.2 2006/07 growing season

7.4.2.2.1 Insiza district

Rainfall was poorly distributed at each of the farms used in the 2006/07 growing season. The total seasonal rainfall was 456, 402, 297 and 343 mm for Nyathi, Mpofu, Mguni and Mlalazi farms respectively (Fig. 7.5). The growing season started on day 50 (19 November) and ended on day 192 (10 April), and an average of 19 wet days were recorded across the farms in ward 1 of Insiza district. Although the growing season was longer than the 74 year record (Chapter 4), rainfall distribution during the season was very erratic resulting in crop failure on most of the farms used in the 2006/07 season. The highest daily rainfall event was 75 mm recorded on day 92 (31 December 2006) at Nyathi farm. A 42-day dry spell was recorded between days 92 and 134 in ward 1 of Insiza district during 2006/07 growing season (Fig. 7.5).

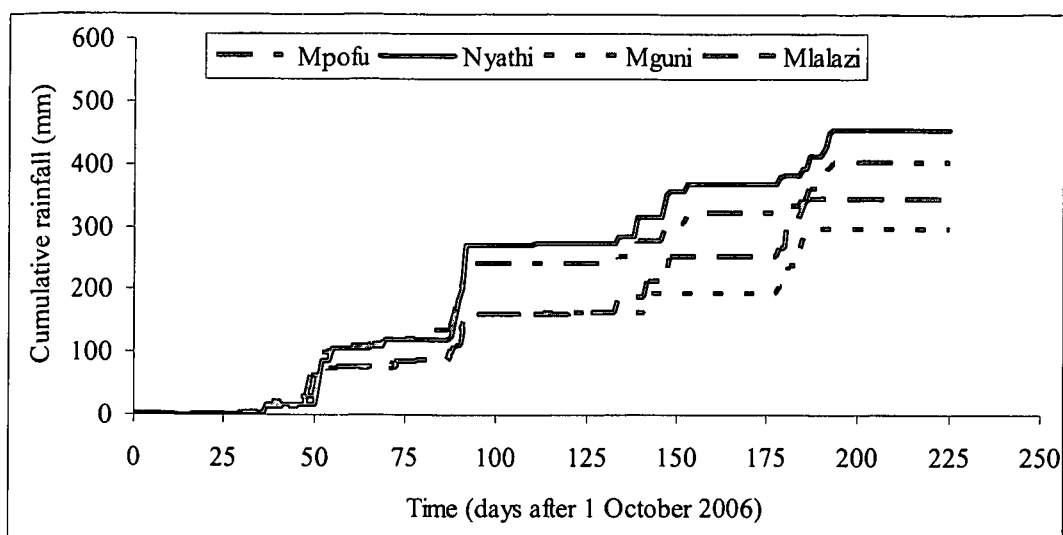


Figure 7.5. Cumulative rainfall distribution at Mpofu, Nyathi, Mguni and Mlalazi farms of ward 1 in Insiza district during 2006/07 growing season

Despite the below average rainfall observed across the study sites, soil water regimes did respond to each rainfall event at Mpofu and Nyathi farms. The basin tillage system consistently had the highest profile water content during 2006/07 season (Fig. 7.6). Profile water content decreased in all tillage systems from day 90 (29 December) to day 145 (22 February). The highest profile water content was recorded on day 90 (29 December) with CP having 57 mm, DP recording 70 mm, ripper had 75 mm and 80 mm for the basin system. The high profile water content recorded on day 90 (29 December) is attributed to the 60 - 63 mm of rain that was accumulated across the farms between the soil water measurements on day 75 (14 December) and 90 (29 December).

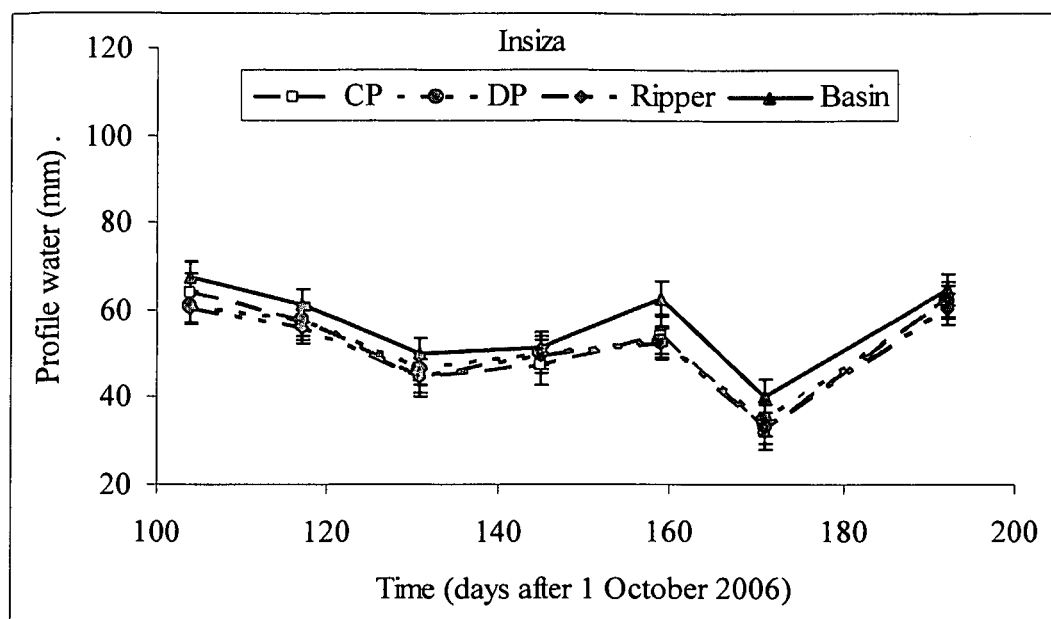


Figure 7.6. Profile soil water changes (0 – 0.60 m) averaged across two farms (Mpofu and Nyathi) in ward 1 of Insiza district during 2006/07 growing season. Error bars represent standard errors of means

7.4.2.2.2 Gwanda district

Rainfall was poorly distributed at each of the three farms used in the 2006/07 season. Total seasonal rainfall was 238, 243 and 317 mm for Sibanda, Siziba and J. Ncube farms respectively (Fig. 7.7). The growing season started on day 54 (23 November) and ended on day 187 (5 April) with 14 wet days being recorded during the season. As observed in Insiza district, rainfall distribution was erratic during the season despite the length of the season being greater than the long term averages reported in Chapter 4. A 55 day dry spell was recorded in ward 17 of Gwanda district between days 94 and 149 during the 2006/07 growing season (Fig. 7.7). The highest daily rainfall event was 50 mm recorded on 31 December 2006 and 28 March 2007 at John Ncube farm while the other farmers recorded less.

There were little differences in the total profile water content in the four tillage systems throughout the whole season, with values remaining around 50 mm. The

profile soil water responses to rainfall events were quite similar in the four tillage systems in a season that had below average rainfall (Fig. 7.8).

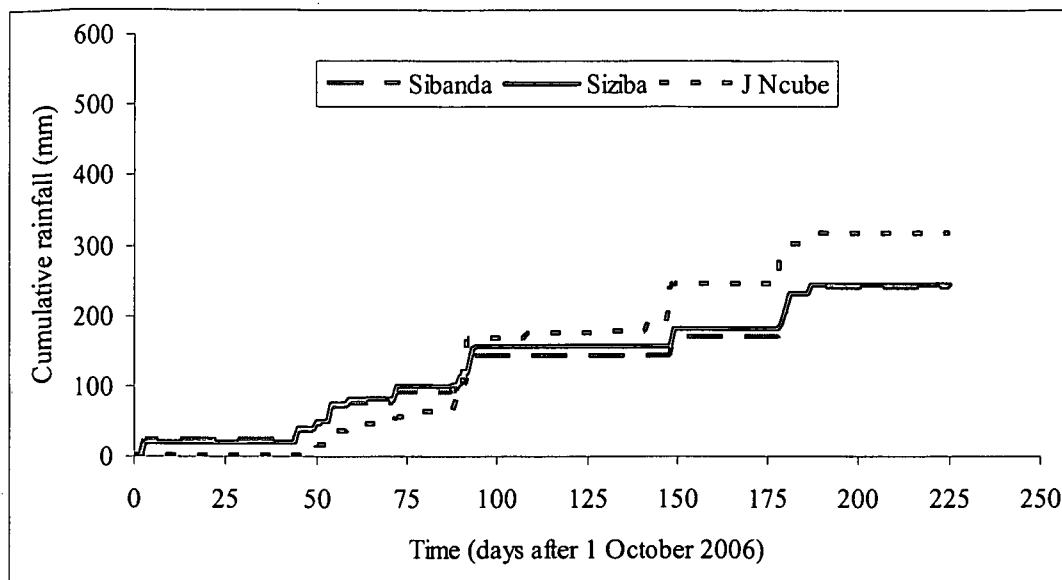


Figure 7.7. Cumulative rainfall distribution at Sibanda, Siziba and J. Ncube farms of ward 17 in Gwanda district during 2006/07 growing season

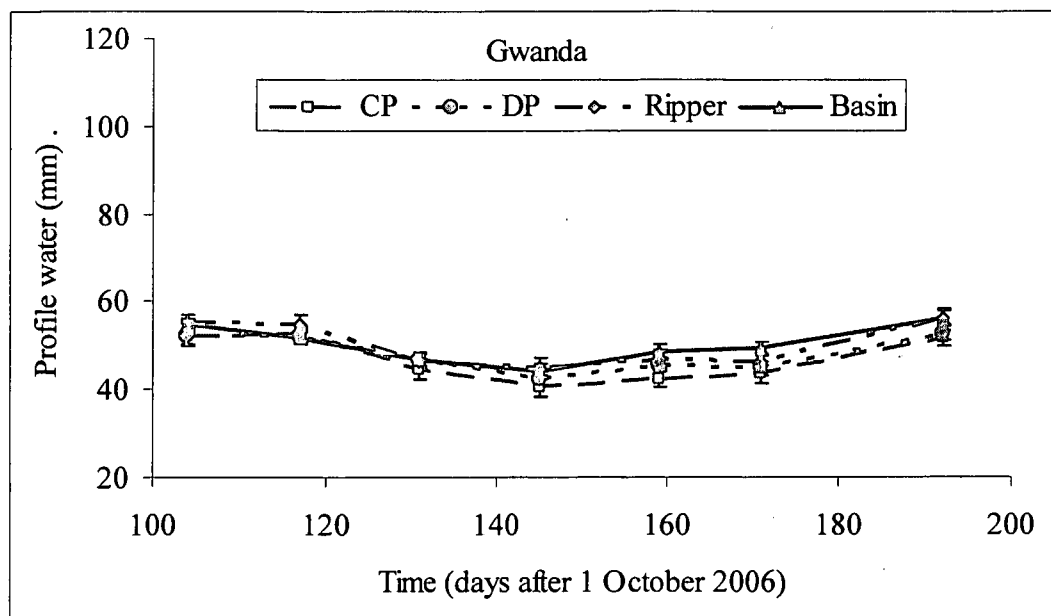


Figure 7.8. Profile soil water changes (0 – 0.60 m) averaged across three farms (Sibanda, Siziba and J. Ncube) in ward 17 of Gwanda district during 2006/07 growing season. Error bars represent standard errors of means

7.4.2.3 2007/08 growing season

7.4.2.3.1 *Insiza district*

Total seasonal rainfall was 549, 541, 444, 319 and 288 mm for Mpofu, Nkomo, N. Ncube, Mguni and Mlalazi farms respectively compared to long term mean at Filabusi of 546 mm (Fig. 7.9). The growing season started on day 54 (23 November) and ended very early on day 116 (24 January) with an average of 24 wet days being recorded across the five farms. The first half of the growing season was wetter than the second half with five farms receiving more than 60 % of their total seasonal rainfall during the October to December period. The highest daily rainfall event was 50 mm recorded at Mpofu farm on day 100 (8 January 2008).

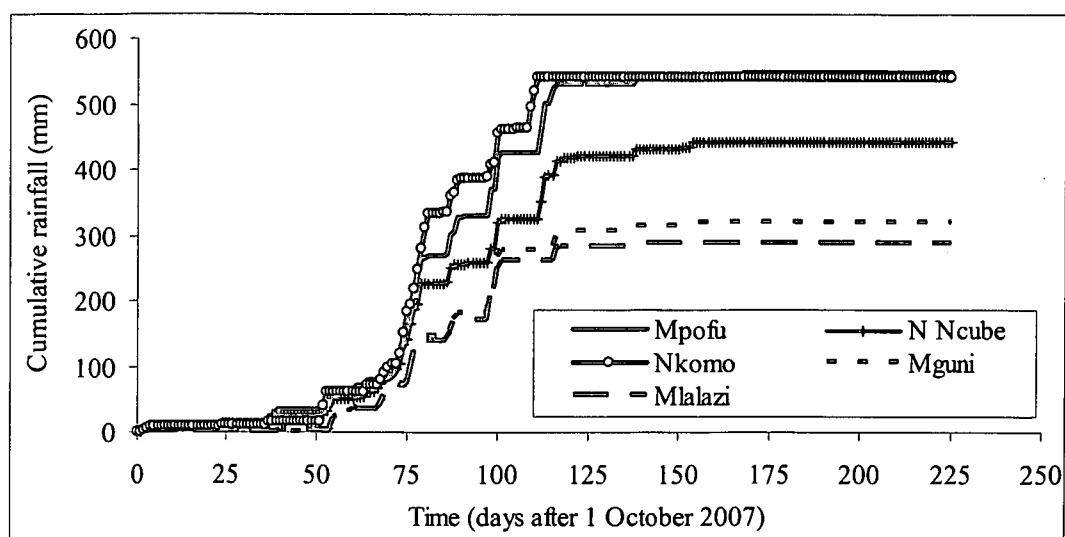


Figure 7.9. Cumulative rainfall distribution at Mpofu, N. Ncube, Nkomo, Mguni and Mlalazi farms of ward 1 in Insiza district during 2007/08 growing season

The rainfall events of November 2007 to January 2008 recharged the soil profiles under all four tillage systems at the three farms during 2007/08 growing season (Fig. 7.10). The conventional tillage system had lowest profile water content from the time the rains ended in January 2008 up to the end of the 2007/08 growing season. Profile water content decreased in each tillage system between days 79 (18 December 2007)

and 99 (7 January 2008). The rainfall events that occurred between days 99 (7 January) and 113 (13 January) resulted in waterlogging in the basin system at Mpofu and Nkomo farms. The soil profile had been recharged previously by 180 mm of rain that was received between days 70 (9 December) and 79 (18 December).

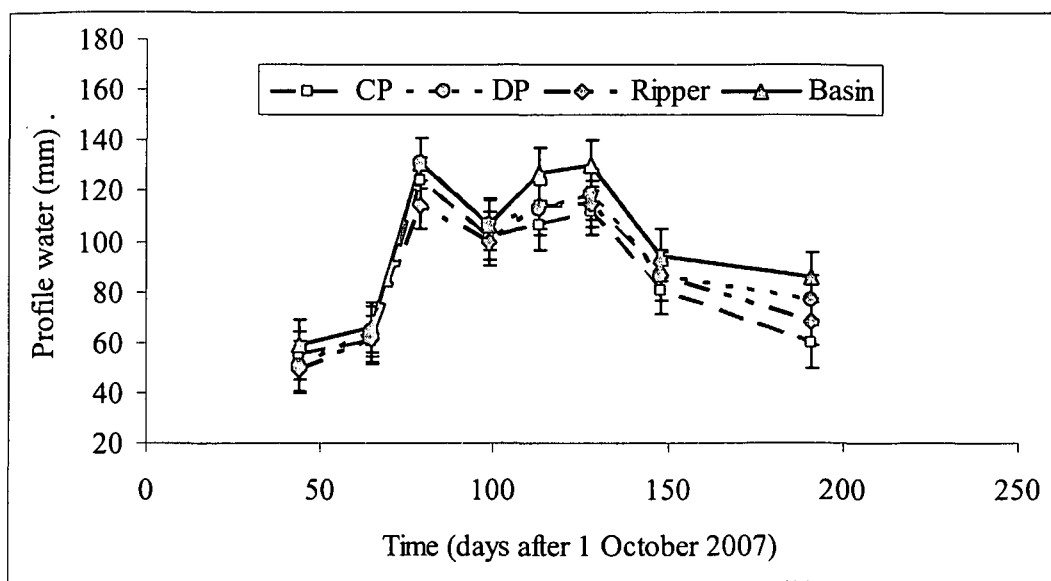


Figure 7.10. Profile soil water changes (0 – 0.60 m) averaged across three farms (Mpofu, N. Ncube and Nkomo) in ward 1 of Insiza district during 2007/08 growing season. Error bars represent standard errors of means

7.4.2.3.2 *Gwanda district*

The growing season in Gwanda district was also characterised by an early cessation of the rains in January 2008 as observed in Insiza district. The total seasonal rainfall was 265, 225, 243 and 303 mm for Sibanda, Siziba, John Ncube and Tlou farms respectively (Fig. 7.11). The growing season started on day 78 (17 December) and ended on day 118 (26 January) and only 15 wet days were recorded during the season. The highest daily rainfall event of 75 mm was recorded at John Ncube farm on day 100 (8 January). As observed in Insiza district the first half of the season was wetter than the January-March period. Each farm in Insiza district received more than 65 % of its total seasonal rainfall during the first half of the growing season.

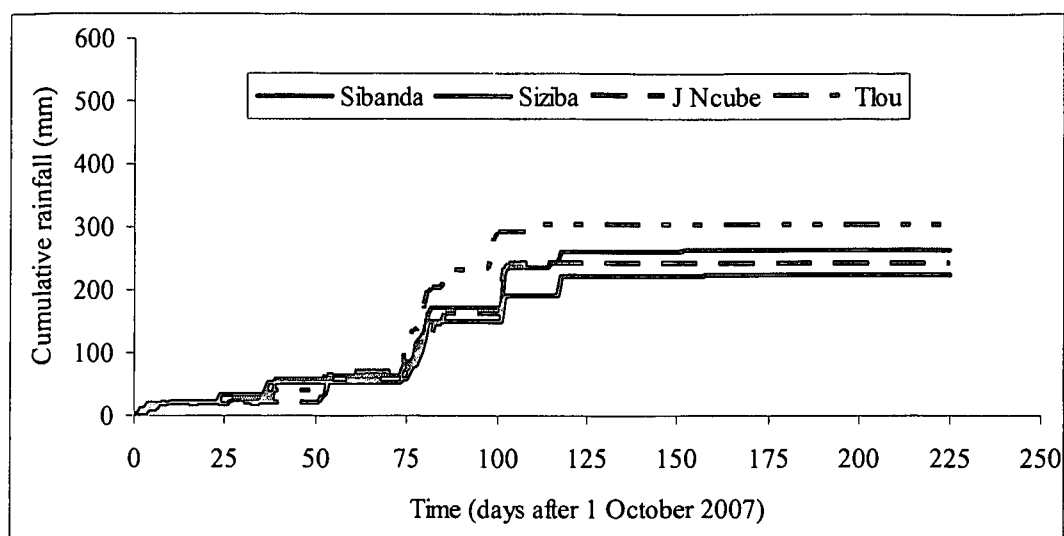


Figure 7.11. Cumulative rainfall distribution at Sibanda, Siziba, J. Ncube and Tlou farms of ward 17 in Gwanda district during 2007/08 growing season

Profile soil water responses to rainfall events were quite similar in the four tillage systems across the three farms where soil water was monitored during the 2007/08 season (Fig. 7.12). The highest profile water content was recorded on day 101 (9 January) following 40-75 mm rainfall events recorded across the three farms (J. Ncube, Sibanda and Siziba). The CP system had the lowest profile water content for most periods of the 2007/08 season when soil water was measured. In contrast to observations made in Insiza district, there was no waterlogging in the basin system at any of the three farms in Gwanda district.

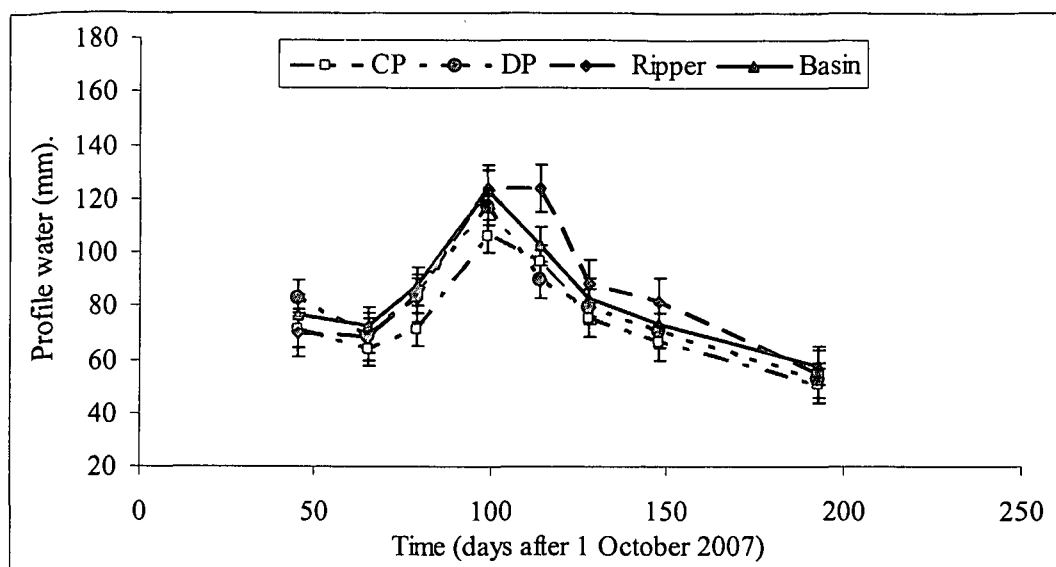


Figure 7.12. Profile soil water changes (0 – 0.60 m) averaged across three farms (J. Ncube, Sibanda and Siziba) in ward 17 of Gwanda district during 2007/08 growing season. Error bars represent standard errors of means

7.4.3 Surface runoff

7.4.3.1 2006/07 growing season

The observed seasonal runoff water losses from four tillage treatments are summarized in Fig. 7.13. Runoff water losses differed significantly ($P < 0.001$) across the four farms. The highest runoff water losses were recorded at Mpofu and Nyathi farms of Insiza district with sandy to loamy sand soil types. The least runoff water losses were recorded at Sibanda farm which has sandy soil and lies in the southern most part of ward 17 of Gwanda district. Tillage treatment had a significant ($P = 0.003$) effect on runoff water losses across the four farms. Planting basins had the least water losses. Runoff water losses from single and double conventional ploughing, and ripper tillage treatments were comparable at all farms. At Ncube farm runoff water losses from all four tillage treatments were not significantly different.

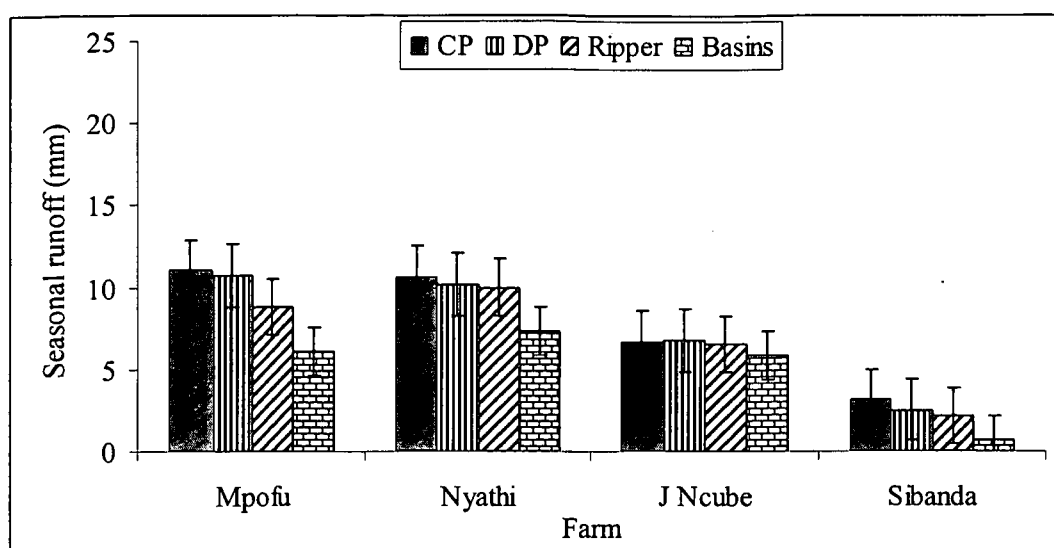


Figure 7.13. Seasonal runoff losses from plots under four tillage systems in 2006/07 growing season, Insiza (Mpofu and Nyathi) and Gwanda (J. Ncube and Sibanda) districts. Error bars are standard error of differences between means

7.4.3.2 2007/08 growing season

Total seasonal runoff measured differed significantly ($P < 0.001$) across the four farms. Mpofu and N. Ncube farms located in Insiza district had higher surface runoff losses than J. Ncube and Sibanda of Gwanda district (Fig. 7.14). Planting basin tillage system had the lowest measurable surface runoff in both districts. In the CP and DP tillage systems Mpofu and N. Ncube farms experienced double the amount of surface runoff than that measured at J. Ncube and Sibanda in the same tillage treatments.

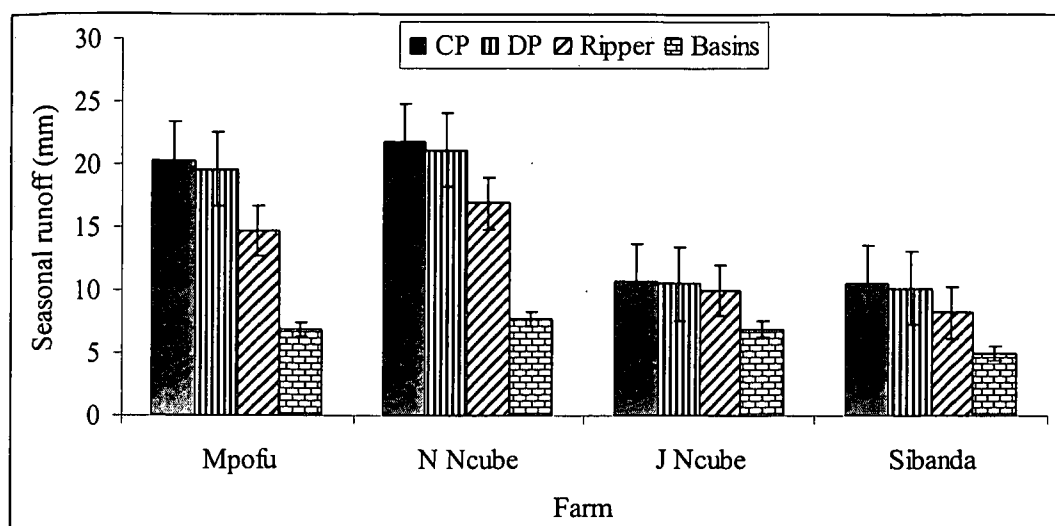


Figure 7.14. Seasonal runoff losses from plots under four tillage systems in 2007/08 growing season, Insiza (Mpofu and N. Ncube) and Gwanda (J. Ncube and Sibanda) districts. Error bars are standard error of differences between means

7.4.4 Maize performance

7.4.4.1 Maize plant stand

In the 2005/06 growing season, planting basin system had better maize crop establishment at all the five farms used in 2005/06 season (Table 7.2). In the 2005/06 season, the basin system had 11 % more plants per m² than CP and DP systems. In the relatively dry 2006/07 season, the basin system had 75 % and 31 % more plants than CP, and both DP and ripper systems. In 2007/08 season DP, ripper and basin systems had 11, 22 and 39 % more plants per unit area than CP system.

Table 7.2. Average maize plant stands (plants m⁻²) under four tillage systems (CP, DP, ripper and basin) measured two weeks after crop emergence during the three seasons of experimentation in Insiza and Gwanda districts

Tillage system	2005/06	2006/07	2007/08
CP	2.7	1.2	1.8
DP	2.7	1.6	2.0
Ripper	2.9	1.6	2.2
Basins	3.0	2.1	2.5
Lsd _{0.05}	0.20	0.37	0.27
CV (%)	5.1	27	15

7.4.4.2 Maize yields

7.4.4.2.1 2005/06 growing season

The main tillage and nitrogen effects on maize crop performance are given in Table 7.3. The tillage system and nitrogen fertilizer had no significant ($P > 0.05$) influence on maize grain production and harvest index during the relatively wet 2005/06 growing season. Nitrogen increased maize stover ($P < 0.05$) production regardless of tillage system used. The two-way tillage system x nitrogen interaction had no significant ($P > 0.05$) influence on grain and stover production.

Table 7.3. Maize responses to four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0 and 10 kgNha⁻¹) averaged across five farms in 2005/06 season, Insiza and Gwanda districts

Treatment		Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index
Tillage	CP	1 173	2 236	0.34
	DP	1 403	2 316	0.39
	Ripper	1 086	2 093	0.36
	Basins	1 250	2 398	0.36
	Lsd _{0.05}	442	328	0.063
Nitrogen	0	1 123	2 015	0.36
	10	1 315	2 499	0.35
	Lsd _{0.05}	313	232	0.045
	CV (%)	32	13	18

7.4.4.2.2 2006/07 growing season

The tillage system had no significant ($P = 0.25$) influence on maize grain production during the 2006/07 season. In contrast, nitrogen fertilizer increased grain ($P = 0.023$) and stover ($P < 0.001$) production during the 2006/07 growing season (Table 7.4). Maize harvest index was not influenced by the tillage system nor amount of nitrogen applied. The two-way tillage system x nitrogen interaction had no significant ($P > 0.05$) effect on maize grain and stover production, nor harvest index.

Table 7.4. Maize responses to four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer averaged across three farms in 2006/07 season, Insiza and Gwanda districts

Treatment		Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index
Tillage	CP	304	704	0.29
	DP	593	1 013	0.36
	Ripper	349	1 130	0.23
	Basins	418	937	0.29
	Lsd _{0.05}	213	343	0.092
Nitrogen	0	282	710	0.28
	10	413	943	0.29
	20	554	1 184	0.30
	Lsd _{0.05}	185	297	0.080
	CV (%)	40	29	25

7.4.4.2.3 2007/08 growing season

In the 2007/08 season the tillage system had no significant ($P > 0.05$) effect on maize grain and stover production at the seven farms in Gwanda and Insiza districts (Table 7.5). Nitrogen significantly ($P < 0.001$) increased maize grain and stover production during the 2007/08 growing season (Table 7.5). The two-way tillage system x nitrogen interaction had a significant ($P = 0.004$) influence on grain production across seven farms scattered within Insiza and Gwanda districts (Table 7.5). For the 0 kgNha⁻¹, conventional system had the lowest grain yield while DP system had the highest yield across the seven farms. Under the 10 kgNha⁻¹ treatment, the basin system had the highest grain production. Maize grain production decreased with further increase in nitrogen application rate from 10 to 20 kgNha⁻¹ in the DP, ripper and basin tillage systems.

Table 7.5. Maize responses to four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0, 10 and 20 kgNha⁻¹) averaged across seven farms in 2007/08 season, Insiza and Gwanda districts

Tillage system	N applied (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index
CP	0	413	889	0.25
	10	704	1 030	0.31
	20	714	1 027	0.33
DP	0	782	1 209	0.31
	10	700	1 434	0.29
	20	196	747	0.20
Ripper	0	518	1 211	0.28
	10	652	1 417	0.28
	20	447	867	0.28
Basins	0	702	1 164	0.30
	10	875	1 290	0.34
	20	254	729	0.17
	Lsd _{0.05} (tillage)	285	524	0.078
	Lsd _{0.05} (N)	144	79	0.032
	Lsd _{0.05} (interaction)	361	536	0.092
	CV (%)	45	14	23

7.4.4.2.4 *Across seasons comparison*

The seasons had a significant ($P < 0.001$) influence on maize grain and stover produced, and harvest index observed under each tillage system. Maize yield was significantly lower in 2006/07 season at all N quantities applied compared with 2005/06 and 2007/08 seasons. The two-way interaction of season and tillage system significantly influenced grain production ($P = 0.001$). In all three seasons the DP system gave higher grain yields than the other tillage treatments (Table 7.6). The two-way season x nitrogen fertilizer interaction had a significant ($P = 0.006$) influence on grain yield (Table 7.7). Nitrogen increased maize grain production in all tillage systems even in the 2006/07 and 2007/08 seasons with below average rainfall pattern.

Table 7.6. Effects of season and tillage system on maize crop performance during three seasons of experimentation in Insiza and Gwanda districts

Season	Tillage system	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index
2005/06	CP	1 144	2 163	0.34
	DP	1 510	2 588	0.37
	Ripper	1 057	2 020	0.36
	Basins	1 222	2 325	0.36
2006/07	CP	304	704	0.29
	DP	593	1 013	0.35
	Ripper	349	1 130	0.23
	Basins	418	937	0.29
2007/08	CP	495	883	0.29
	DP	732	1 223	0.36
	Ripper	456	1 125	0.29
	Basins	675	1 107	0.34
Lsd _{0.05} (tillage x season interaction)		498	529	0.082
CV (%)		43	35	19

Table 7.7. Effects of season and nitrogen fertilizer on maize crop performance during three seasons of experimentation in Insiza and Gwanda districts

Season	N applied (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index
2005/06	0	1 123	2 015	0.36
	10	1 315	2 499	0.35
2006/07	0	282	710	0.28
	10	413	943	0.29
	20	554	1 184	0.30
2007/08	0	432	843	0.28
	10	604	1 118	0.32
	20	733	1 293	0.35
Lsd _{0.05} (nitrogen)		223	273	0.063
Lsd _{0.05} (nitrogen x season interaction)		326	354	0.054
CV (%)		26	35	18

7.4.4.3 Water use efficiency (WUE)

There was no significant ($P > 0.05$) differences in water use efficiency across the four tillage treatments in 2005/06 growing season (Figs. 7.15 and 7.16). Nitrogen fertilizer had no significant effect on water use efficiency during the relatively wet 2005/06 season. In the 2006/07 growing season water use efficiency could not be calculated because soil water was not monitored on farms where maize was harvested. In the 2007/08 season, N fertilizer significantly ($P < 0.001$) increased WUE in all tillage systems (Fig. 7.16). At 20 kgNha⁻¹ CP, DP, ripper and basin tillage systems recorded WUE of 1.2, 2.0, 2.0 and 2.1 kg ha⁻¹ mm⁻¹.

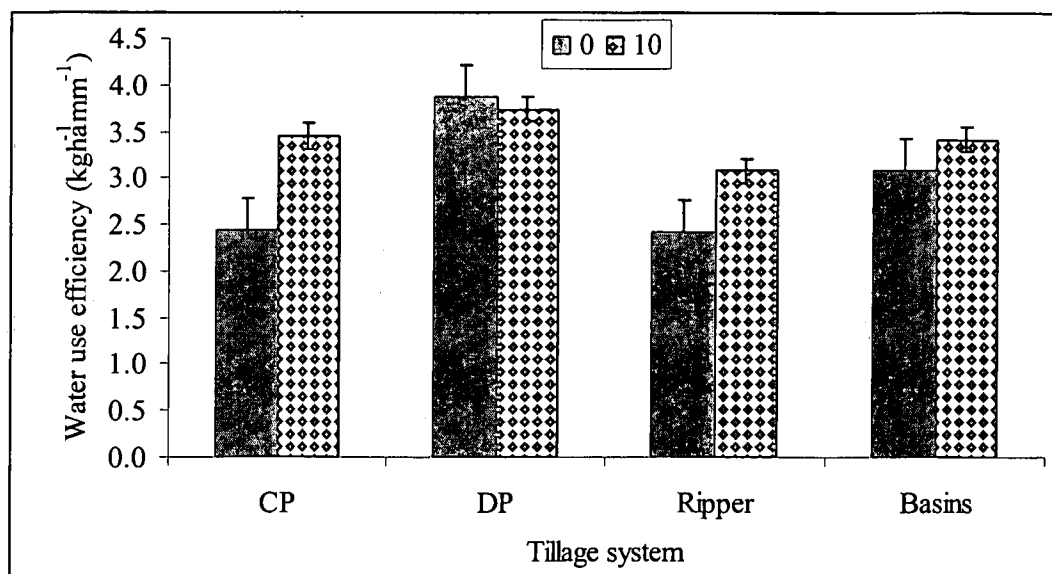


Figure 7.15. Water use efficiency as affected by four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0 and 10 kgNha⁻¹) across five farms (Moyo, Mpofu, J. Ncube, Sibanda and Siziba) in 2005/06 season, Insiza and Gwanda districts. Error bars stand for standard error of differences between means

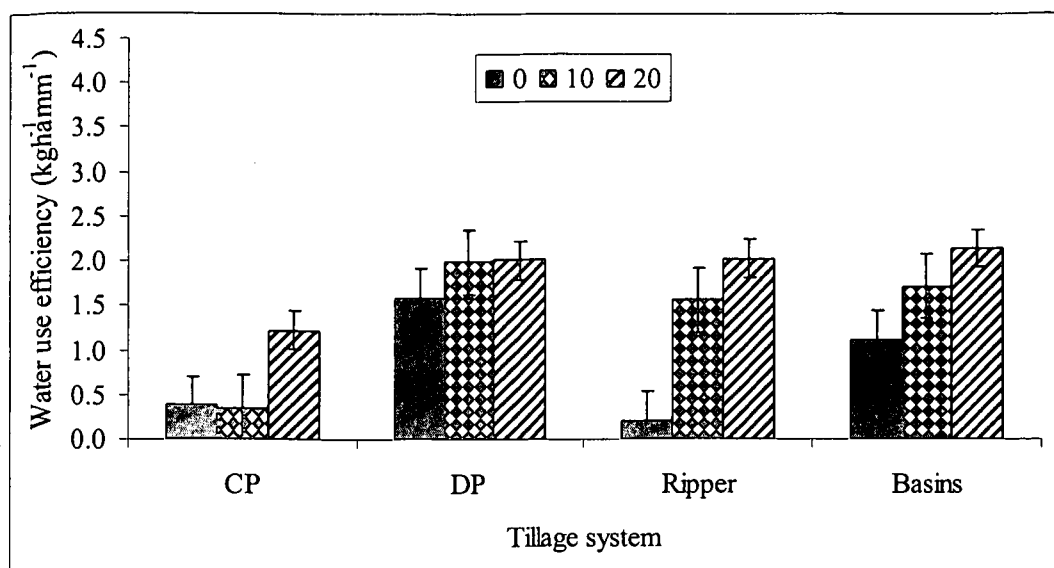


Figure 7.16. Water use efficiency as affected by four tillage systems (CP, DP, ripper and basin) and nitrogen fertilizer (0, 10 and 20 kgNha⁻¹) across six farms in 2007/08 season, Insiza and Gwanda districts. Error bars stand for standard error of differences between means

7.4.4.4 Agronomic nitrogen use efficiency (ANUE)

Agronomic nitrogen use efficiency (ANUE) calculated for the different growing seasons and tillage systems are summarized in Table 7.8. In 2005/06 growing season with above average rainfall pattern single ploughing treatment had the highest ANUE with double ploughing recording the lowest. In the 2006/07 season with below-average rainfall pattern, double ploughing treatment gave the highest ANUE and single ploughing recorded the lowest agronomic nitrogen use efficiency. In 2007/08 season, the ripper system had higher ($P = 0.054$) ANUE compared with the other three tillage systems.

Table 7.8. Agronomic nitrogen use efficiency of maize in four tillage systems (CP, DP, ripper and basin) averaged across farms for each season during 2005/06, 2006/07 and 2007/08 growing seasons Insiza and Gwanda districts

Tillage method	2005/06	2006/07	2007/08
CP	26.0	9.1	11.0
DP	6.7	24.0	3.1
Ripper	9.8	10.0	28.0
Basins	12.0	11.0	23.0
Lsd _{0.05}			19
CV (%)	42	53	18

7.5 Discussion

7.5.1 Seasonal rainfall patterns

Rainfall distribution at each farm in Insiza and Gwanda districts differed during the 2005/06, 2006/07 and 2007/08 seasons. The 2005/06 season recorded above average and well distributed rainfall between December 2005 and April 2006 in both Insiza and Gwanda districts. The total rainfall recorded at each farm in Insiza district was similar to the 74 year average for Insiza district (Chapter 4). However, for Gwanda district total rainfall recorded at each farm was less than 376 mm which is the 50 year average rainfall for Beitbridge which is drier than Gwanda district (Chapter 4). Rainfall was below average in 2006/07 season when 47 to 150 mm was received between 28 December 2006 and 1 January 2007. In this drought year, total rainfall at each farm was less than 546 mm which is the 74 year average for the Filabusi meteorological station located in Insiza district. Similar dry spells observed during the 2006/07 growing season in southern Zimbabwe have been reported in other years (Oosterhout, 1996). The dry spells ranging from 42 days in Insiza district and 50 days in Gwanda led to significant yield reductions and complete crop failure at 75 % of the farms. The large variation in rainfall observed in the 2006/07 and 2007/08 growing seasons is typical of the Mzingwane catchment and has been reported in other studies (Chibulu, 2007; Masvaya *et al.* 2008; Love *et al.*, 2008).

7.5.2 Soil water regimes and surface runoff

The four tillage systems harvested different quantities of rainwater with planting basins having consistently higher soil water content at the start of season (Figs. 7.2, 7.4 and 7.10). The high initial soil water content in planting basin system probably explain the better maize crop establishment observed at most of the farms (Table 7.2). From the on-station experiments, relatively high soil water content in the basin system was also observed on clay soil where mulch cover was superimposed on top of conventional, ripper and basin tillage systems (Chapter 9a; Mupangwa *et al.*, 2007). The tillage treatments affected soil surface microtopography to varying degrees. The grid of 0.9 m x 0.6 m spaced planting basins created a higher surface roughness compared to the other tillage treatments resulting in superior rainwater harvesting and better promotion of infiltration. As observed by Guzha (2004) the higher the surface roughness the greater the potential for surface depression water storage. As the season progressed the planting basin structure did not collapse completely as the basins were partially filled with soil. This allowed continued harvesting of rainwater up to the last rainfall event of the season in April. In the 2007/08 season, waterlogging was experienced only at Mpofu and Nkomo farms of Insiza district. The soil profile under the basin system maintained relatively higher soil water content until the last measurement was taken on 12 April 2008 (Fig. 7.12). No waterlogging was experienced in Gwanda district because of the lower rainfall received in the district compared to Insiza during the 2007/08 season.

Although the double spring ploughed system started off with higher soil water content at some farms (Figs. 7.8 and 7.12), its rainwater harvesting ability decreased substantially as the growing season progressed. This initial high soil water content

under ploughing can be attributed to increased porosity of the soil following loosening during tillage operations and the short lived surface depressions (Bruneau and Twomlow, 1998). Initially ploughing reduces bulk density, increases porosity and infiltration capacity of the surface soil layer (Unger and Stewart, 1983; Das and Chopra, 1988; Sasal *et al.*, 2006; Van der Meer, 2000). However, as the season progresses compaction begins in the surface soil layer resulting in a reduction in soil porosity. Consequently infiltration capacity of the surface soil layer decreases as a result of reduced pore space (Shinde *et al.*, 1982). Furrows created by tine ripping were easily filled with soil as the season progressed and this resulted in reduced rainwater harvesting ability of that tillage system.

The loosening of soil during ploughing coupled with surface crusting could have promoted high runoff losses measured under single and double conventional tillage systems. The heavy rainfall events observed could have promoted soil surface sealing and crusting, and reduced infiltration (Al-Qinna and Abu-Awwad, 2001; Bouman, 2007) thereby increasing surface runoff from ploughing and ripping tillage treatments. As the season progressed soil surface depressions disappear in all four tillage treatments but the decline was least in planting basin experimental plots. The better surface storage in planting basin system explains reduced surface runoff measured in 2006/07 and 2007/08 seasons in the basin system (Figs. 7.13 and 7.14).

7.5.3 Maize crop performance

Seasonal rainfall pattern had a strong impact on maize crop performance during the three year study period. Soil water could have been the major growth limiting factor in 2006/07 and 2007/08 given the rainfall distribution patterns observed during the

two seasons. The 2006/07 season gave the lowest yields after experiencing dry spells of up to 42 and 50 days in Insiza and Gwanda districts. The dry spells occurred during the flowering stage of the hybrid maize variety (SC403) grown in the trials. Maize is more sensitive to water stress at flowering and grain filling stages (NeSmith and Ritchie, 1992; Otegui *et al.*, 1995; Otegui and Bonhomme, 1998; Pandey *et al.*, 2000). Cakir (2004) conducted a three year study on a silty loam soil to determine the most water stress sensitive stage of maize. The results from the study showed that soil water stress during flowering and ear formation stages significantly reduce grain yield. Otegui *et al.* (1995) also report that soil water stress during maize flowering and silking stages reduces yield because these are the stages when kernel number on each maize cob is defined.

Maize crop responded differently to tillage systems during the 2005/06, 2006/07 and 2007/08 growing seasons. Incessant rains were observed between planting in December 2005 and February 2006 during the 2005/06 growing season. Soil water was not a limiting factor to maize crop growth and the effect of tillage systems on rainwater harvesting was eliminated in that season with above average rainfall. In the 2006/07 and 2007/08 seasons with below average rainfall, planting basin, ripper and double ploughing systems improved maize performance compared with single conventional ploughing system (Tables 7.4 and 7.5). The improved performance of maize crop can be attributed to more soil water availability in the double ploughing, planting basin and ripper systems compared to single conventional ploughing. In the ripper and basin tillage systems the improved yields could also be attributed to improved soil fertility along rip furrows and in basins. The same rip furrows and planting basins received manure before planting in 2006/07 and 2007/08 seasons.

Addition of nitrogen fertilizer increased maize yield even in the dry 2006/07 growing season. Nitrogen is one of the major yield limiting nutrients in Zimbabwean soils (Mapfumo and Giller, 2001). Maize yield responses to N fertilizer were small in the wet 2005/06 season and this can be attributed to the smaller quantity of 10 kgNha^{-1} applied in a growing season that received a lot of rainfall between January and February 2006. Leaching could have been a pathway through which some of the applied N was lost during a growing season with above average rainfall. Mapfumo and Giller (2001) report that leaching is a common pathway of N loss especially on granite derived sandy soils. Positive maize yield responses to N in our study are consistent with observations made in previous studies in semi-arid southern Zimbabwe (Ncube *et al.*, 2007; Twomlow *et al.*, 2008b). The wide scale promotion of N fertilizer use in semi-arid southern Zimbabwe showed maize yield gains of 30-100 % following application of 10 kgNha^{-1} on smallholder farms (Twomlow *et al.*, 2008b). Studies by Ncube *et al.* (2007) in western Zimbabwe revealed a significant maize yield gain through combining 3-6 tha^{-1} of manure with 10 kgNha^{-1} . In the 2006/07 growing season 20 kgNha^{-1} gave an extra maize yield benefit over the 10 kgNha^{-1} treatment across the farms. The decrease in grain yield following the application of 20 kgNha^{-1} in the double ploughing, ripper and basin tillage systems is unusual given the low fertility status of soils used in this study (Table 7.1). The low maize harvest index and suppressed grain yield could have been a result of soil water stress during the grain filling stage of the crop. Effective grain filling in maize is highly dependant on the availability of assimilates and these are significantly influenced by soil water availability (Maddonni *et al.*, 1998).

7.5.4 Water and Agronomic Nitrogen Use Efficiency

Nitrogen fertilizer improved water use efficiency in all tillage treatments (Fig. 7.15 and Fig. 7.16). Increase in water use efficiency following application of N fertilizer could be attributed to faster root and shoot development which promotes more effective water and nutrient uptake (Gaiser *et al.*, 2004). The soil surface gets covered quickly thereby reducing non-productive water losses such as soil evaporation. Our study showed highest water use efficiency in double ploughed, ripper and basin systems in response to 10 and 20 kgNha⁻¹. This observation could be attributed to maize roots being able to explore deeper for water and nutrients in the three systems. Plant nutrients placed in the vicinity of the crop in the ripper and basin systems and this, coupled with more favourable soil water conditions, could have led to better crop performance and hence higher water use efficiency. Water use efficiency increased with increase in applied nitrogen. Increase in water use efficiency following application of N fertilizer under semi-arid conditions has also been observed by Ncube *et al.*, (2007) in Tsholotsho district of south western Zimbabwe.

Calculated agronomic nitrogen use efficiencies averaged 14, 14 and 16 kg grain per kg of N applied for 2005/06, 2006/07 and 2007/08 seasons. The applied N was probably used more efficiently in 2005/06 season when soil water was not limiting compared to 2006/07 and 2007/08 seasons which had soil water deficits during critical stages of maize growth. The observed ANUE in our study were lower than 31-53 kg grain per kg N achieved in a study by Ncube (2007) in Tsholotsho district of western Zimbabwe. Differences in seasonal rainfall amounts and their distribution during the growing season could explain the differences in ANUE observed in Matebeleland South (Insiza-Gwanda districts) and Matebeleland North (Tsholotsho

district). The efficient use of applied N could have been significantly influenced by management especially effective weed control on the farms.

7.6 Conclusion

This study has demonstrated that under semi-arid smallholder conditions, the performance of single and double conventional ploughing, ripper and basin tillage systems depends on the characteristics of the seasonal rainfall. The recommended double spring ploughing and the widely promoted planting basins and ripper tillage systems have similar soil water patterns during seasons with above and below average rainfall pattern. This implies there are equal chances of experiencing reduced crop yields or total crop failure in the event of a drought or prolonged dry spell if a farmer is any one of the tested four tillage systems. Planting basin tillage system harvests more rainwater at the beginning of the season and this promoted better maize crop establishment compared with the ripper and conventionally ploughed systems. The basin tillage system also reduced surface runoff significantly across all farms and soil types. The surface depressions created by planting basins reduced surface runoff and promoted infiltration resulting in better soil profile recharge compared with ripper, single and double ploughing. However, the higher soil water content early in the season and reduced surface runoff in the basin system was not translated into substantial differences in water use efficiency, agronomic nitrogen use efficiency and grain yield gains compared with the other tillage systems.

The rainwater harvesting ability of ripper and basin systems is reduced during the season as rip furrows and basins fill up with soil. Double ploughing does have the potential of harvesting and storing early rains as effective as planting basin and ripper

tillage systems but its soil water collection ability is lost as the growing season progresses. Timing of the first ploughing in the double ploughed system could be critical so that the early spring rains are captured and stored in the soil profile. Single and double ploughing systems give similar crop yields to ripper and planting basin systems in a growing season with above-average rainfall. However, in a season with below-average rainfall the double ploughing tillage system gave similar or slightly more maize yield benefits compared with ripper and planting basin systems.

Nitrogen fertilization with 10 kgNha^{-1} on granitic sandy soils in a season with above-average rainfall in semi-arid areas gives insignificant yield gains. In a drought year nitrogen fertilizer improves maize yields especially in double ploughing, ripper and planting basin systems. Application of nitrogen fertilizer increases water and agronomic nitrogen use efficiency, and yields regardless of the tillage system used. Results from our study further suggest that soil water management techniques and nitrogen fertilizer are required concurrently in semi-arid smallholder cropping systems.

CHAPTER 8

Effect of Dead Level Contours and Infiltration Pits on Soil Water Content and Crop Yields on Smallholder Farms in Gwanda District, Southern Zimbabwe

8.1 Introduction

Water harvesting is a method of collecting surface runoff from a catchment area and storing the water in the root zone of a cultivated area for crop growth (Li *et al.*, 2004). In rainfed agriculture of the semi-arid areas rainwater harvesting could be a source of water for smallholder cropping systems. Traditionally smallholder farmers in Zimbabwe have been using the graded contour ridge for safely diverting excess water from the field (AGRITEX, undated). A standard graded contour ridge is pegged at a gradient of 1:250 and contour ridges are usually spaced at 20 to 30 m apart on gentle slopes (AGRITEX, undated; Hughes and Venema, 2005).

In semi-arid areas dead level contours, pegged at zero gradient, are an appropriate field technique for harvesting runoff water for crop production. The purpose of a dead level contour is to retain runoff water in the contour and the water will move into cropped field by lateral flow (Hughes and Venema, 2005). To improve the ability of the dead level contour in retaining runoff, water infiltration pits are dug along the contour often at 10 m interval (AGRITEX, undated). A standard infiltration pit measures 2 m long, 1 m wide and 0.5 – 1 m deep (AGRITEX undated; Hughes and Venema, 2005).

Efforts by international research organisations, NGOs and Government Agricultural Departments continue in finding a combination of appropriate technologies that try to reduce the impact of harsh climatic factors on people's livelihoods. In Gwanda district of southern Zimbabwe dead level contours and infiltration pits are being promoted by Practical Action Southern Africa. The design of the contours includes having an infiltration pit or storage tank at certain intervals along the contour (Plate 8.1). Dead level contours and infiltration pits have been explored in other semi-arid districts of Zimbabwe (Motsi *et al.*, 2004; Mugabe, 2004). Results from these earlier studies have shown that dead level contours and infiltration pits can contribute towards soil water status in the cropped field. This chapter reports on a study to investigate the in-field soil water content supplied by dead level contours with and without infiltration pits in semi-arid Gwanda district of southern Zimbabwe.



Plate 8.1. Dead level contours with (a) storage tank at Magaya farm and (b) with infiltration pit at Ncube farm in Humbane village of ward 17, Gwanda district

8.2 Objectives

The current study in Gwanda district was designed to quantify soil water content supplied by dead level contours with and without infiltration pits at four farms in ward 17. At the end of the 2007/08 summer growing season pearl millet and maize yields were measured along the transects between specified distances from the contours. The specific objectives of study were:

- (1) to measure the profile soil water content at 7 and 2 m upslope, and at 3, 8, 13 and 18 m downslope of the dead level contours with and without infiltration pits through the growing season;
- (2) to determine the extent to which soil water moves laterally from contours into the cropped field;
- (3) to determine the soil water balance at different distances from the dead level contour with and without infiltration pit; and
- (4) to measure crop yields and water use efficiency at different distances from the dead level contour with and without infiltration pit.

8.3 Materials and Methods

8.3.1 *Experimental set up*

The average depth of the dead level contour at Ncube farm was 0.30 m with a width of 1.0 m. At Moyo farm, the dead level contour had an average depth of 0.3 m and width of 0.9 m. The infiltration pit at Dube farm measured 1.5 m long, 1.0 m wide and 0.4 m deep compared with the pit at Siziba which measured 1 m long, 0.5 m wide and 0.3 m deep.

Moyo and Ncube farms are located 4 - 5 km apart while Dube and Siziba farms are about 3 km apart.

8.3.2 Soil water and crop yield data collection

During both the 2006/07 and 2007/08 seasons volumetric soil water content was measured using a capacitance probe (*microgopher sensor type*). Depth of access tubes varied between 0.6 and 0.8 m across the four farms. Depth of access tubes was restricted by the presence of a lateritic layer in the profile at Ncube and Moyo farms in Gwanda district. Soil water was measured fortnightly at 0.1 m depth increments during both 2006/07 and 2007/08 seasons. Soil water content in millimetres was determined by multiplying volumetric water content by thickness of each layer where the soil water was measured. The soil water content in the 0 – 0.6 m profile at each farm was calculated during the 2006/07 and 2007/08 growing seasons.

Soil texture was determined by the hydrometer method as outlined by Anderson and Ingram (1993). The lower limit of the soil at each farm was derived from the soil water content on a day when the lowest profile soil water content was measured through the season although this date varied from farm to farm. The drained upper limit was derived from the day that had the highest profile soil water content at least 18 hours after a rainfall event of 30 mm or more. The plant available water capacity (PAWC) at each farm was calculated as the difference between the drained upper limit (DUL) and lower limit (LL). The DUL was derived from soil water content measured on 19 December 2007 (day 70) at Dube, Siziba and Ncube farms. The DUL for Moyo farm was derived

from soil water content measured on 9 January 2008 (day 101). The LL for Dube and Siziba farms was derived from soil water content measured on 14 November 2007 (day 45). The LL for Ncube and Moyo farms was derived soil water content measured on 5 December 2007 (day 66). The components of the water balance measured were rainfall (P) and change in profile soil water content (ΔS) from the beginning to the end of season and these were used to derive evapotranspiration (ET) at each distance from the contour (Equation 8.1).

$$ET = P \pm \Delta SW \quad \text{Equation 8.1}$$

where calculated ET (mm) is seasonal evapotranspiration, P (mm) is total seasonal rainfall and ΔSW (mm) is the sum of differences in soil water content measured on different days of the growing season when soil water measurements were taken.

Crop yields were measured from a net plot area of 10 m^2 between adjacent access tubes.

Water use efficiency was calculated as follows:

$$WUE (\text{kgha}^{-1}\text{mm}^{-1}) = Y / ET \quad \text{Equation 8.2}$$

where WUE is water use efficiency ($\text{kgha}^{-1}\text{mm}^{-1}$), Y is either above ground biomass or grain yield (kgha^{-1}) and ET is the evapotranspiration (mm). The evapotranspiration value used to calculate WUE between two adjacent access tubes was an average of the two ET values for the adjacent access tubes along the ploughed transect.

8.3.3 Soil water and crop yield data analysis

Soil water data were analyzed by analysis of variance (ANOVA) using unbalanced design because depth to which access tubes were sunk differed across the four farms (Dube, Siziba, Moyo and Ncube). Crop data was analyzed by ANOVA using the general analysis of variance design (Genstat Discovery Edition 3). All statistical analyses were conducted using Genstat Discovery Edition 3 (www.vsni.co.uk). The least significant difference (Lsd) at 5 % significance level was used to compare means.

8.4 Results and Discussion

8.4.1 Characteristics of the soils for the four farms

Soil water characteristics derived from the soil water data collected during 2007/08 season from Moyo, Ncube, Dube and Siziba farms are given in Figure 8.1. Dube and Siziba farms had dead level contours with infiltration pits while Ncube and Moyo farms had only dead level contours. Plant available water capacity (PAWC) for Moyo, Ncube, Dube and Siziba farms were 36, 40, 48 and 40 mm based on a soil profile of 0.65 m depth. The higher plant available water recorded at Dube farm could be attributed to the high clay content in the soil (Table 8.1) and the bigger infiltration pit on the farm in 2007/08 season. The PAWC for Ncube farm was similar to that measured at Siziba farm although the former had much lower clay content in the profile. The soil profile was recharged by 54 mm of rainfall that was accumulated in two days before soil water measurements were taken at Ncube farm for DUL. At Siziba farm the soil profile was recharged by 40 mm of rain that was accumulated over two days before soil water measurements were taken for DUL.

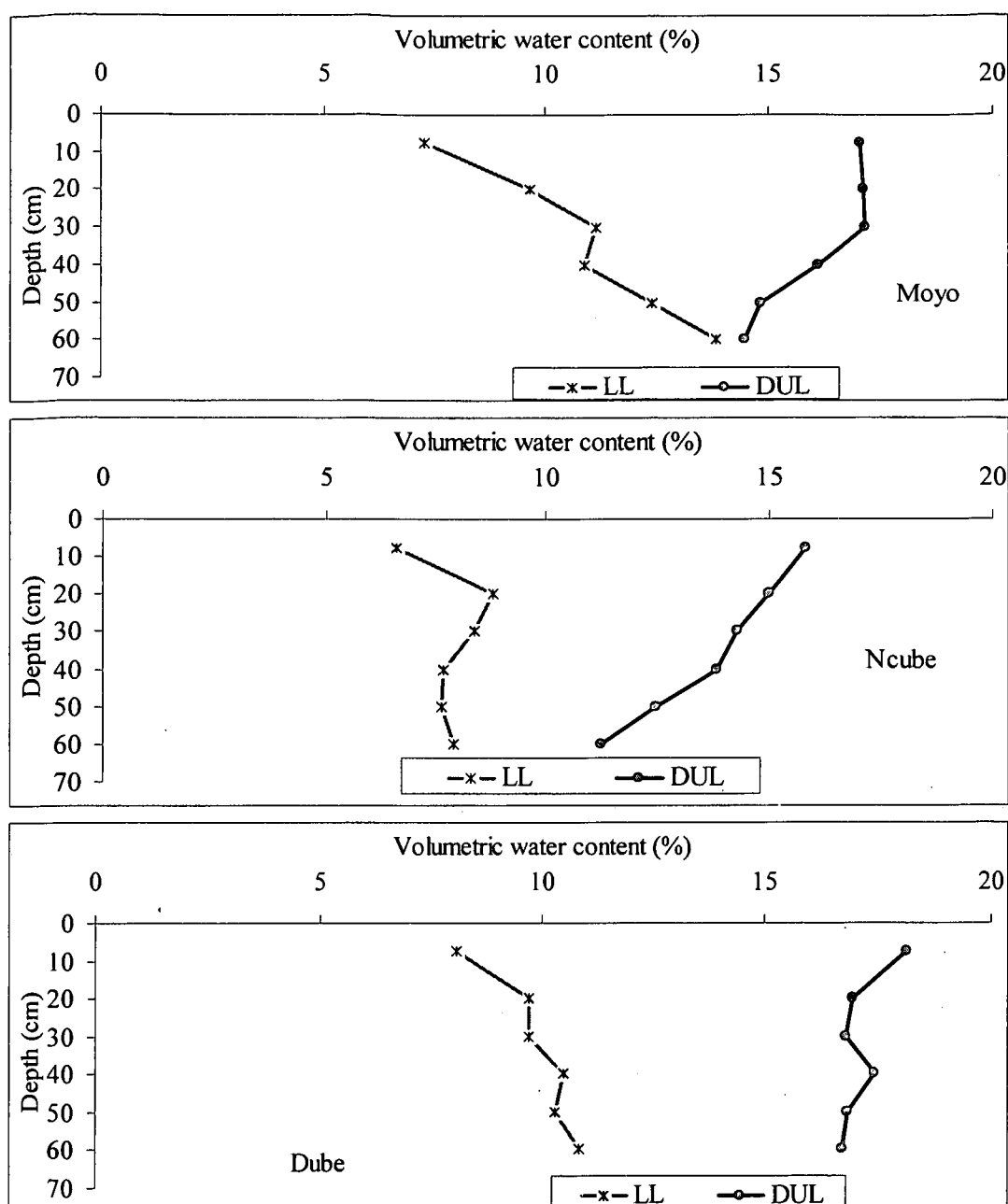


Figure 8.1. Drained upper limit (DUL) and lower limit (LL) derived from 2007/08 soil water data for Moyo, Ncube and Dube farms in Gwanda district

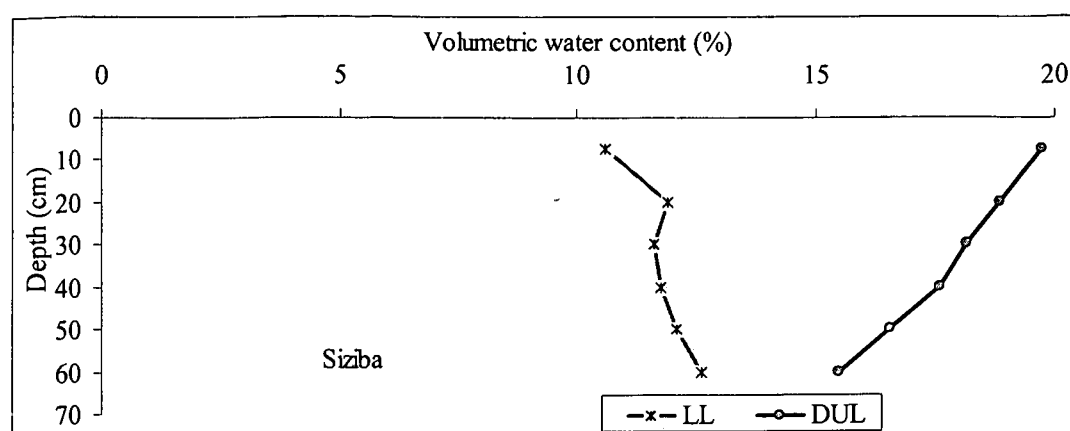


Figure 8.2. Drained upper limit (DUL) and lower limit (LL) derived from 2007/08 soil water data for Siziba farm in Gwanda district

Table 8.1. Soil textural variation with soil depth at the four farms used for quantifying soil water supply from dead level contours and infiltration pits in Gwanda district

Farm	Structure	Depth (cm)	% clay	% silt	% sand
Moyo	Only dead level contour	0-15	5	3	92
		15-30	6	4	90
		30-45	8	4	88
		45-60	7	8	85
Ncube	Only dead level contour	0-15	4	6	90
		15-30	3	5	92
		30-45	2	8	90
		45-60	4	7	89
Dube	Dead level contour and infiltration pit	0-15	10	4	86
		15-30	11	3	86
		30-45	16	6	78
		45-60	18	6	76
Siziba	Dead level contour and infiltration pit	0-15	6	13	81
		15-30	12	7	81
		30-45	18	6	76
		45-60	20	7	73

8.4.2 Seasonal rainfall at selected farms

8.4.2.1 2006/07 growing season

The four farms received different amounts of rainfall during the 2006/07 growing season (Fig. 8.3). The number of rainfall events recorded at the four farms ranged from eight recorded at Ncube farm to 17 received at Siziba farm. The total season rainfall recorded

during the 2006/07 growing season ranged from 145 mm recorded at Ncube farm to 242 mm received at Siziba farm. Moyo and Dube farms received 208 and 203 mm of rain during the 2006/07 growing season. The soil water data obtained from Ncube farm suggests that the farmer did not record some rainfall event(s) that occurred between day 143 (20 February 2007) and day 160 (9 March 2007) as there are changes in soil water content. The rainfall records from Sibanda farm that is located about 3 km north-east of Ncube farm, indicate that there was a rainfall event on 26 February (day 149) and Sibanda farm recorded 20 mm on that day. The other farms (Tlou, Nare and Magaya) which are located within a 5 km radius from Ncube farm also received rainfall on 25 February 2007 (day 143) during the 2006/07 season. So it is reasonable to assume that Ncube farm received some rain that day. The highest daily rainfall event during the 2006/07 season was 38 mm received at Moyo farm on 26 February 2007 (day 149).

A 54-day dry spell was experienced from day 94 (2 January 2007) to day 149 (26 February 2007) when 22 mm of rain was received. Dry spells occurring during the cropping period are common in semi-arid areas (Oosterhout, 1996; Rockström *et al.*, 2003). The total seasonal rainfall recorded at each farm during the 2006/07 season was below the 50 year average of 376 mm for Beitbridge district (NR V) (Chapter 4). The 2006/07 season was classified as a drought in semi-arid southern Zimbabwe.

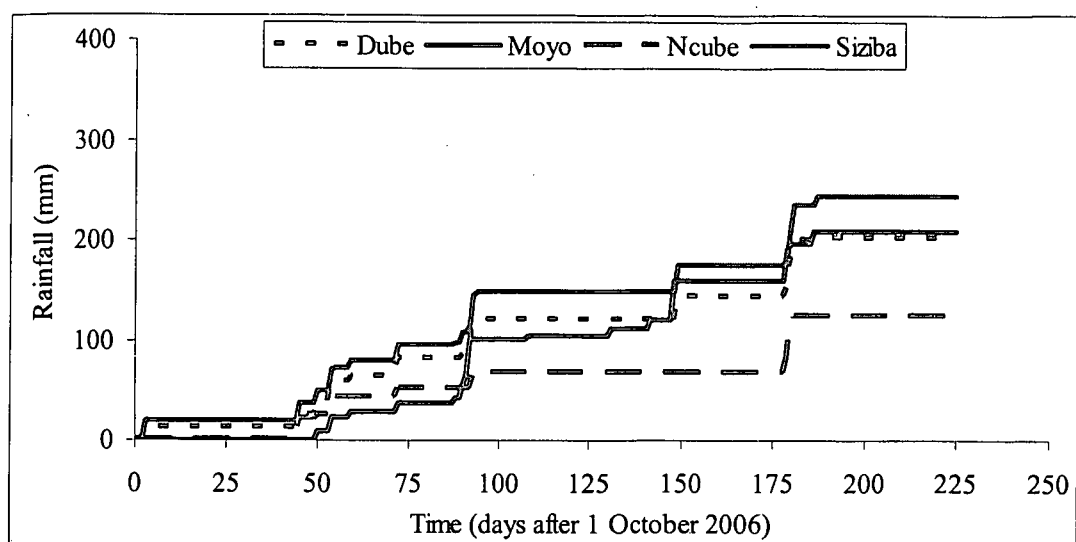


Figure 8.3. Cumulative rainfall distribution at Moyo, Ncube, Dube and Siziba farms of ward 17 in Gwanda district during 2006/07 growing season

8.4.2.2 2007/08 growing season

The number of rainfall events recorded during the 2007/08 season ranged from nine recorded at Moyo farm to 20 recorded at Siziba farm. Dube and Ncube farms received 12 and 11 rainfall events each during the 2007/08 growing season. The total seasonal rainfall ranged from 204 mm recorded at Moyo farm to 298 mm received at Dube farm during the 2007/08 season (Fig. 8.4). The total seasonal rainfall recorded at Ncube and Siziba farms was 289 and 225 mm during the 2007/08 season. Most of the rainfall events were concentrated in the October to December period with just five events occurring during January to April period. The highest daily rainfall event was 70 mm recorded on day 100 (8 January) at Dube, Moyo and Ncube farms. The last rainfall event was recorded on 24 January 2008 (day 116) with 18 to 20 mm being received across Dube, Moyo and Ncube farms. Seasonal rainfall at both farms was below the 50 year 376 mm calculated for Beitbridge district (NR V) (Chapter 4).

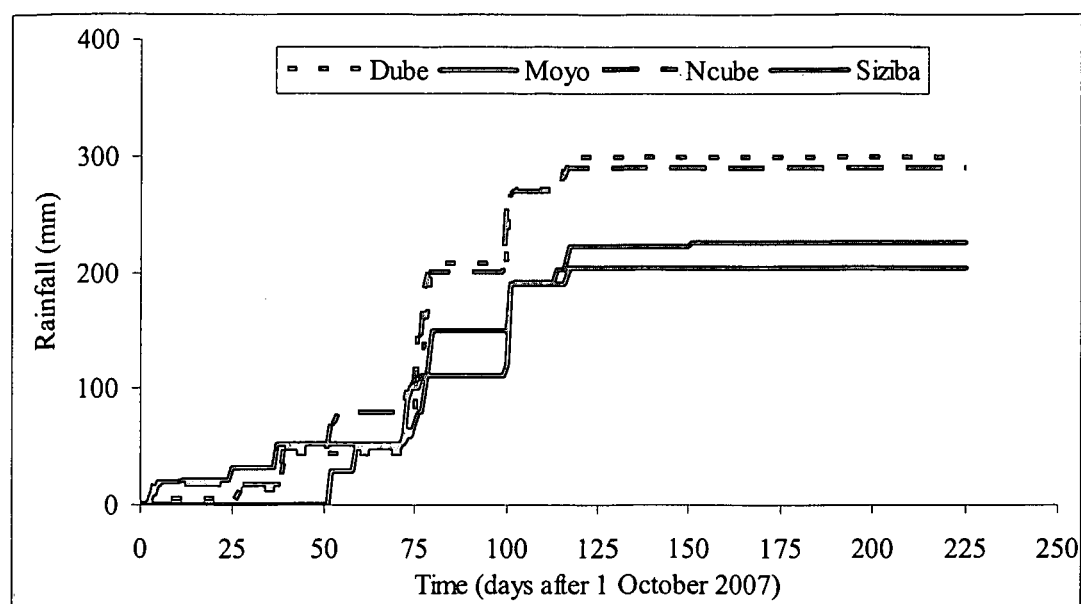


Figure 8.4. Cumulative rainfall distribution at Moyo, Ncube, Dube and Siziba farms of ward 17 in Gwanda district during 2007/08 growing season

8.4.3 Soil water content in fields with dead level contours only

8.4.3.1 2006/07 season

There was no significant ($P > 0.05$) difference between treatments in profile soil water content measured at the six distances from the dead level contour on each day that soil water measurements were taken along the ploughed transect. Profile water content decreased significantly ($P < 0.001$) from day 117 (25 January) to day 142 (19 February) at all distances from the dead level contour (Fig. 8.5). The decrease in profile water content between these two dates is attributed to soil water uptake by crops growing around the access tubes as well soil evaporation. Profile water content decreased by 41 - 48 mm upslope of the dead level contour and 42 - 48 mm downslope of the contour. A 7 mm rainfall event was recorded at Moyo farm between days 117 (25 January) and 142 (19 February) and this amount was negligible to cause any notable changes in profile soil

water content. The soil profiles at Moyo and Ncube farms were recharged by 49 - 57 mm of rain that was received from day 179 (28 March) to day 194 (13 April).

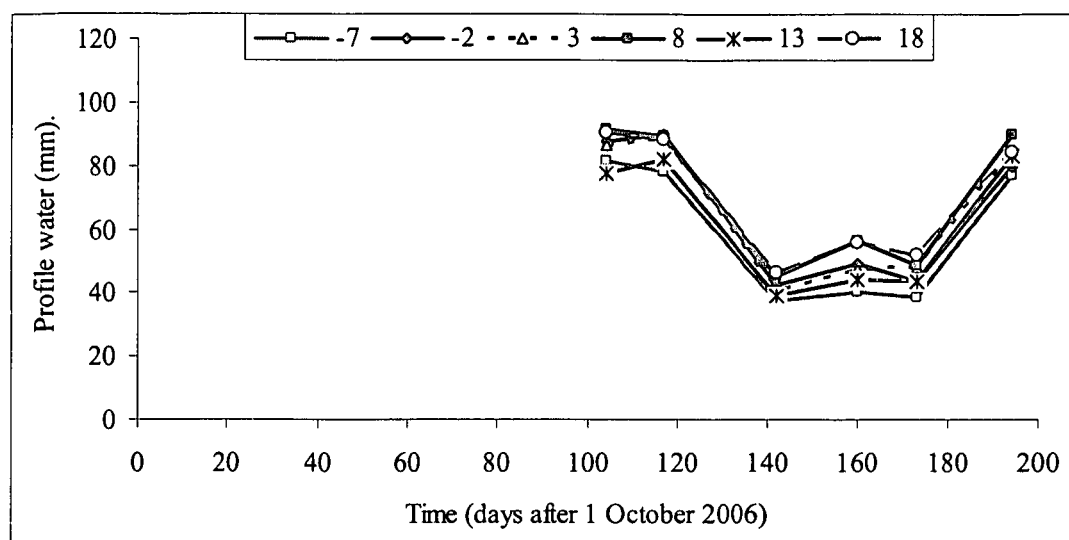


Figure 8.5. Profile soil water changes along ploughed transects averaged across two farms with dead level contours only (Moyo and Ncube) during the 2006/07 growing season

The soil water content measured at each depth was the same ($P = 0.116$) at the six distances from the dead level contour. On 19 February (day 142), the 0 - 0.15 m soil layer was wetter at 3 m from the dead level contour than at the other distances from the contour (Fig. 8.6). The 0.15 - 0.25, 0.35 - 0.45 and 0.55 - 0.65 m soil layers were wettest at 18 m from the dead level contour. On 12 January 2007 (day 104), soil water content at each soil depth was the similar ($P = 0.821$) at five of the six distances from the dead level contour along the ploughed transect. The 0 - 0.15 m layer had more ($P < 0.001$) soil water than the deeper layers at each distance from the dead level contour on 12 January 2007 (day 104).

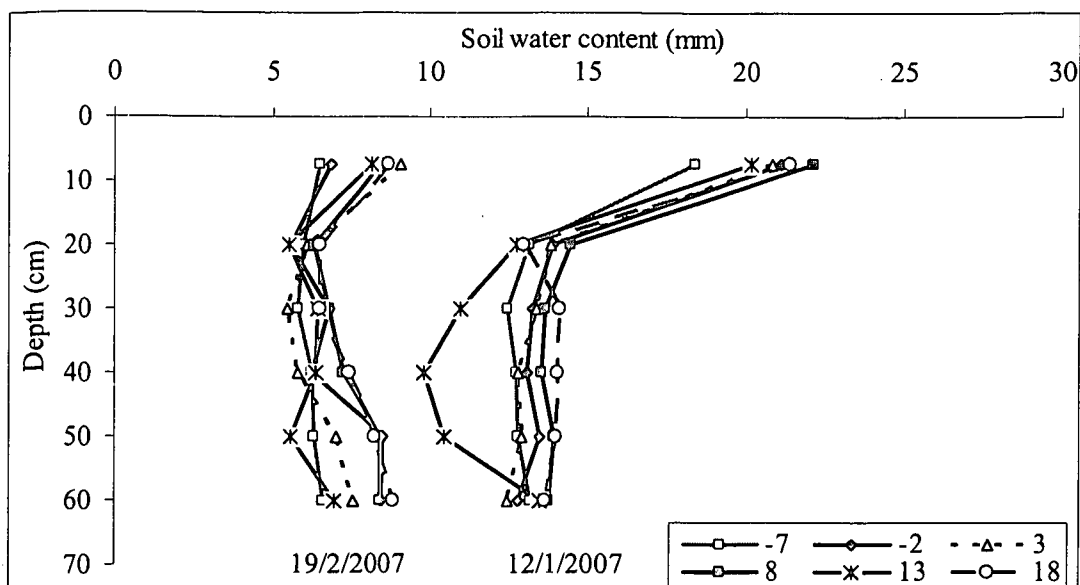


Figure 8.6. Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on the driest day along unploughed (a) and ploughed (b) transects during 2006/07 season

8.4.3.2 2007/08 growing season

Along the unploughed transect, the highest profile soil water content was recorded at 3 m between 14 November 2007 (day 45) and 9 January 2008 (day 101) (Fig. 8.7a). The ploughed transect had more soil water in the profile between 14 November 2007 (day 45) and 24 January 2008 (day 116) (Fig. 8.7b). After receiving 70 mm of rain the night of 8 to 9 January 2008, the measured profile water content ranged from 80 to 83 mm upslope of the dead level contour and 81 mm to 97 mm on the downslope of the dead level contour along the unploughed transect. The highest profile water content of 97 mm was recorded at 3 m downslope of the dead level contour along the unploughed transect. Along the ploughed transect, profile water content ranged from 91 mm to 95 mm on the upslope of the dead level contour and 81 mm to 98 mm on the downslope of the contour. The highest profile water content was recorded at 3 m downslope, suggesting that water

had moved laterally from the dead level contour. There was notable lateral soil water movement following the 70 mm rainfall event recorded at both Moyo and Ncube farms. Conventional ploughing further increased profile water content along the ploughed transect. Ploughing loosens the soil and creates surface depressions that collect rainwater and give it more time to infiltrate (Van der Meer, 2000; Sasal *et al.*, 2006)

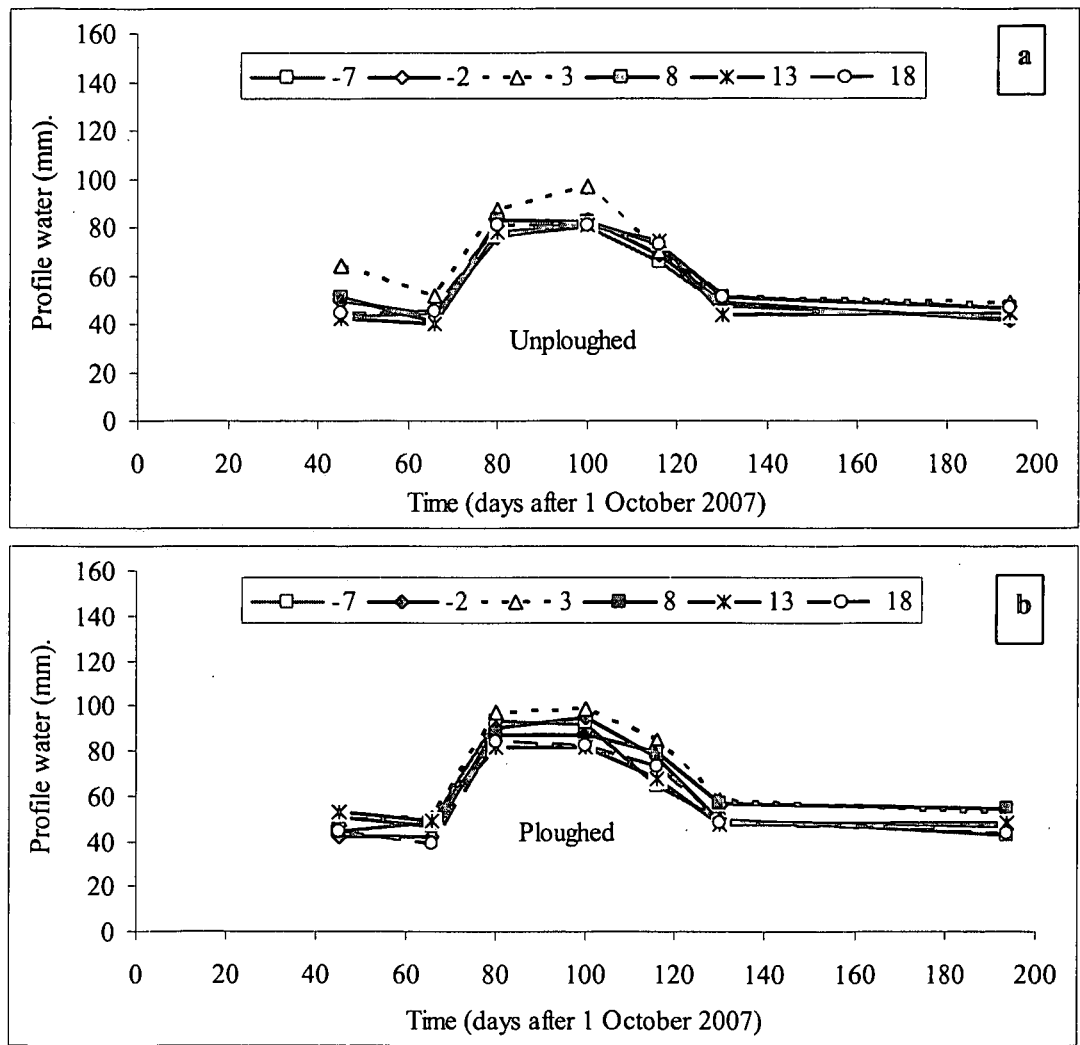


Figure 8.7. Profile soil water changes averaged across two farms (Moyo and Ncube) along unploughed (a) and ploughed (b) transects across farms with only dead level contours during 2007/08 growing season

On one of the driest days during 2007/08 growing season (5 December 2007), the soil water content measured at each soil depth and distance from the dead level contour was the same ($P = 0.205$) along the unploughed and ploughed transects (Fig. 8.8 and 8.9). In the 0.25-0.5 m soil layer, soil water content at 3 m was significantly ($P < 0.001$) higher than at the other distances from the contour along the unploughed transect showing that the difference could be due to lateral flow from the dead level contour. In the 0.25-0.45 m soil layer, soil water content was also higher at 3 m from the contour compared with the other distances along the ploughed transect (Fig. 8.9). The dead level contour supplied soil water to soil layers below 0.25 m.

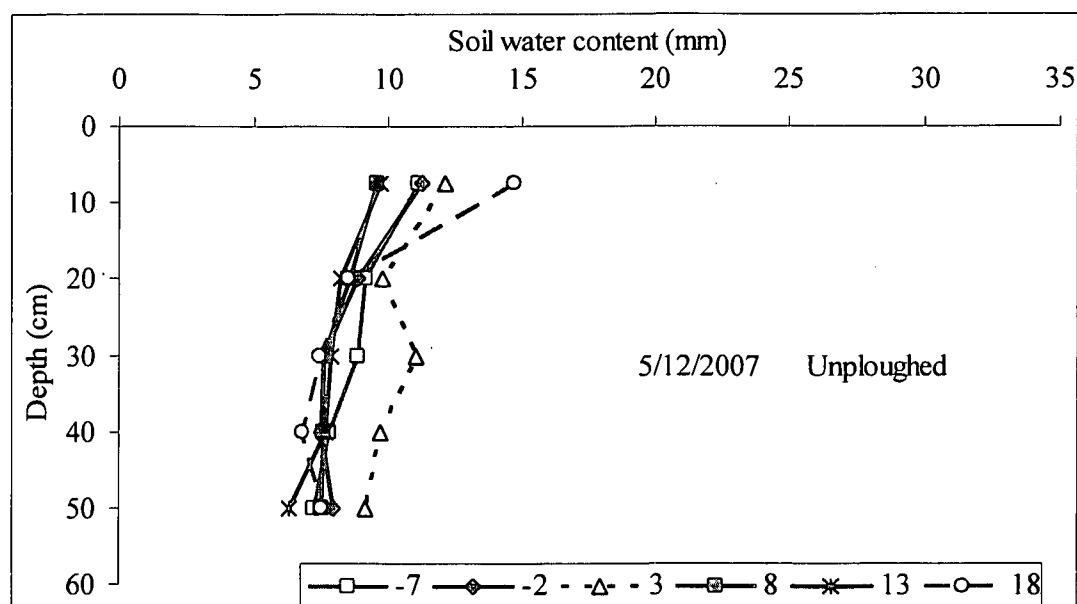


Figure 8.8. Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on the driest day along unploughed transect during 2007/08 season

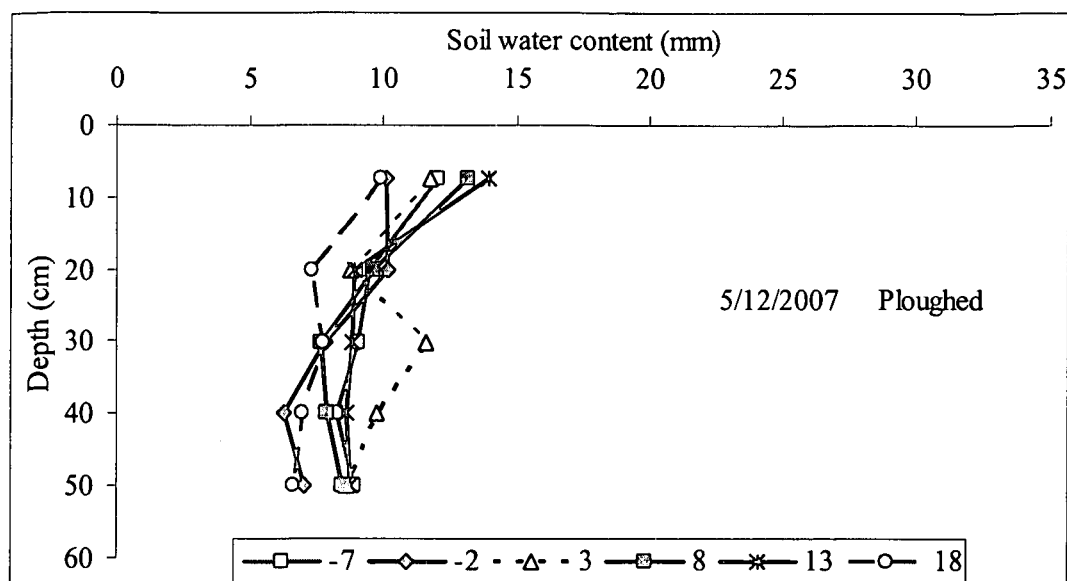


Figure 8.9. Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on the driest day along ploughed transect during 2007/08 season

The 0 – 0.15 m soil layer had significantly ($P < 0.001$) higher soil water content than the deeper layers at each distance from the contour following the 70 mm rainfall event recorded at both farms. The distance from the dead level contour had a significant ($P < 0.001$) influence on soil water content measured at each soil depth along the unploughed and ploughed transects. The highest soil water content at each soil depth was recorded at 3 m along the unploughed transect (Fig. 8.10a). Along the ploughed transect, soil layers starting from 0.2 m depth were wettest at 3 m (Fig. 8.10b). The top soil layer had the highest water content at 2 m upslope. This further confirms that there was lateral soil water movement following the 70 mm rainfall event along both the unploughed and ploughed transects.

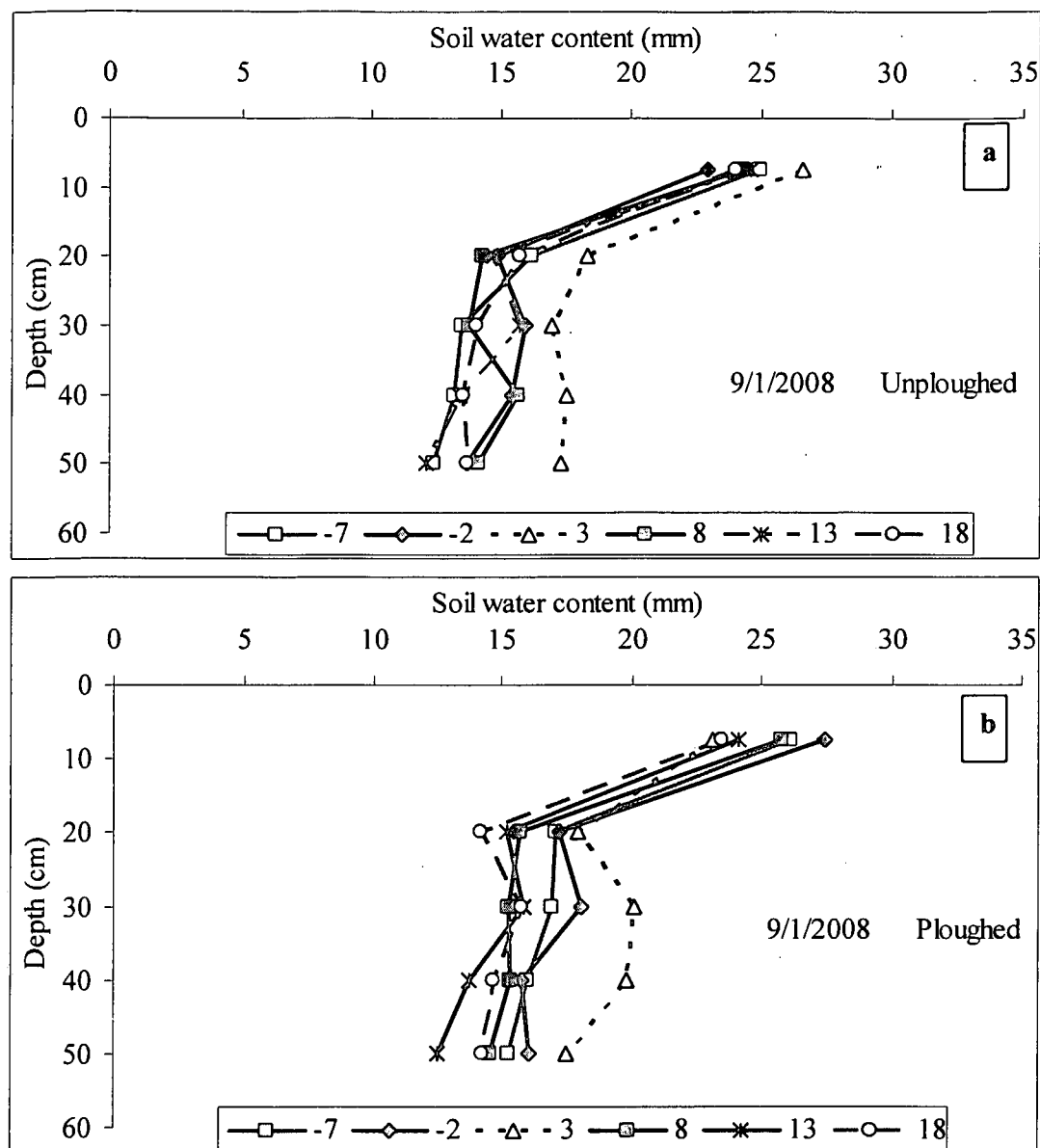


Figure 8.10. Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms (Moyo and Ncube) on wettest day along unploughed (a) and ploughed (b) transects during 2007/08 season

8.4.4 Farms with dead level contours and infiltration pits

8.4.4.1 2006/07 growing season

As observed at farms with dead level contours only, there was no significant ($P > 0.05$) difference in profile soil water content measured at the six distances from the dead level contour and infiltration pit on each day soil water measurements were taken during the 2006/07 season (Fig. 8.11). Profile water content decreased significantly ($P < 0.001$) from day 117 (25 January) to day 142 (19 February) at all the six distances from the dead level contour and infiltration pit. Profile water content decreased by 47 mm upslope of the contour and 36 - 43 mm downslope of the dead level and infiltration pit. The soil profiles were recharged following 22 mm of rainfall recorded at Dube farm and 26 mm at Siziba farm on day 149 (24 February). The rainfall events that occurred between days 179 (28 March) and 194 (13 April) also recharged the soil profiles at both farms with dead level contours and infiltration pits. Dube farm received 60 mm of rain over a nine day period while Siziba farm accumulated 69 mm during the same period. The farms with dead level contours only also received rainfall during the same period. More profile water was gained downslope at farms with dead level contours and infiltration pits than at those farms with dead level contours only. This indicates that the dead level contours and infiltration pits at Dube and Siziba farms captured more rainwater that moved laterally into the field than the dead level contours at Moyo and Ncube farms. Our observation at Dube and Siziba farms are consistently with the findings of Mugabe (2004) that also indicated lateral soil water upslope and downslope of a 7 m long and 1 m deep infiltration pit.

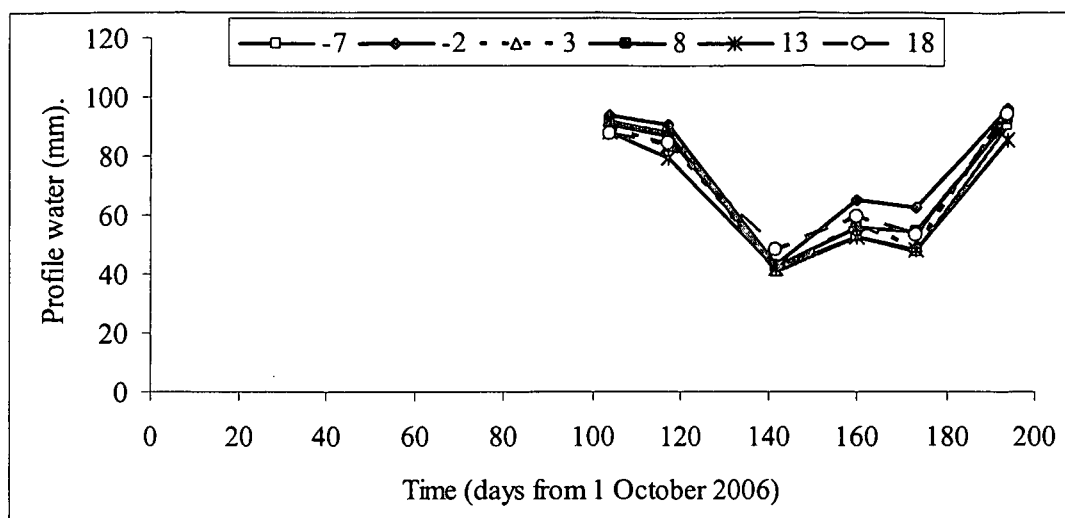


Figure 8.11. Profile soil water changes at different distances from the dead level contour with infiltration pit averaged across two farms (Dube and Siziba) during 2006/07 growing season

Soil water distributions with respect to depth measured on the driest (19 February) and wettest (12 January) days during 2006/07 season at farms with dead level contours and infiltration pits are given in Figure 8.12. The 0 – 0.25 m soil layer had more ($P = 0.042$) soil water at 18 m from the contour than at the other five distances from the contour on one of the driest days (19 February). Soil water content in the 0.25 – 0.6 m layer was similar at the six distances from the dead level contour. The distance from the dead level contour had no significant ($P = 0.985$) influence on soil water content measured at each soil depth along the ploughed transect on 12 January 2007 (day 104). The top soil layer had more ($P < 0.001$) soil water than the deeper layers on 12 January, nine days after a 35 mm rainfall event. The 0 – 0.15 m soil layer had more soil water at 2 m upslope on 12 January (day 104) than at the other distances nine days after the last rainfall event. This suggests that soil water could have moved upslope from the dead level contour through capillary flow.

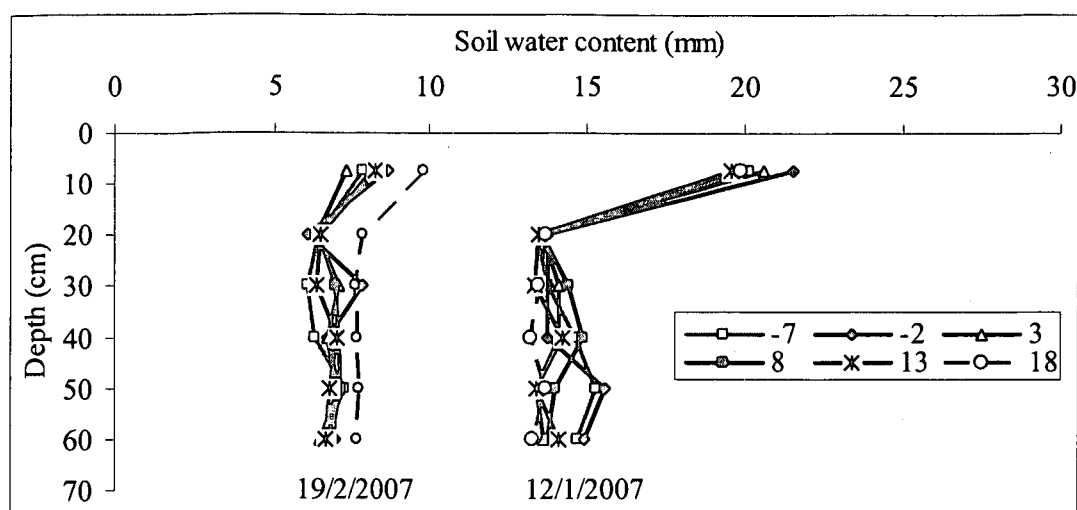


Figure 8.12. Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on driest and wettest days during 2006/07 season

8.4.4.2 2007/08 growing season

As observed at Moyo and Ncube farms, the soil profile along the ploughed transect had more soil water than the unploughed transect. The unploughed transect had the highest profile water content at 18 m from the contour after receiving 60 mm of rainfall during the night of 8 to 9 January 2008 (Fig. 8.13a). There could have been some surface depressions near the access tube at 18 m that were created by ploughing in previous seasons. These depressions collected rainwater during the rainfall event of 8 January (day 100) resulting in the higher soil water measured than at the other five distances from the contour. Soil water content in the profile was the same at 2 and 7 m upslope of the contour but ranged from 111 mm to 118 mm on the downslope of the dead level contour. The lowest profile water content was recorded at 2 m upslope between 14 November 2007 (day 45) and 12 April 2008 (day 194). Along the ploughed transect the highest soil water content in the profile was recorded at 18 m between 9 January 2008 (day 101) and 12 April 2008 (day 194) (Fig. 8.13b). Profile water content ranged from 124 mm to 128

mm on the upslope of the dead level contour while the downslope side recorded 126-138 mm. The highest profile water content was recorded at 18 m from the dead level contour.

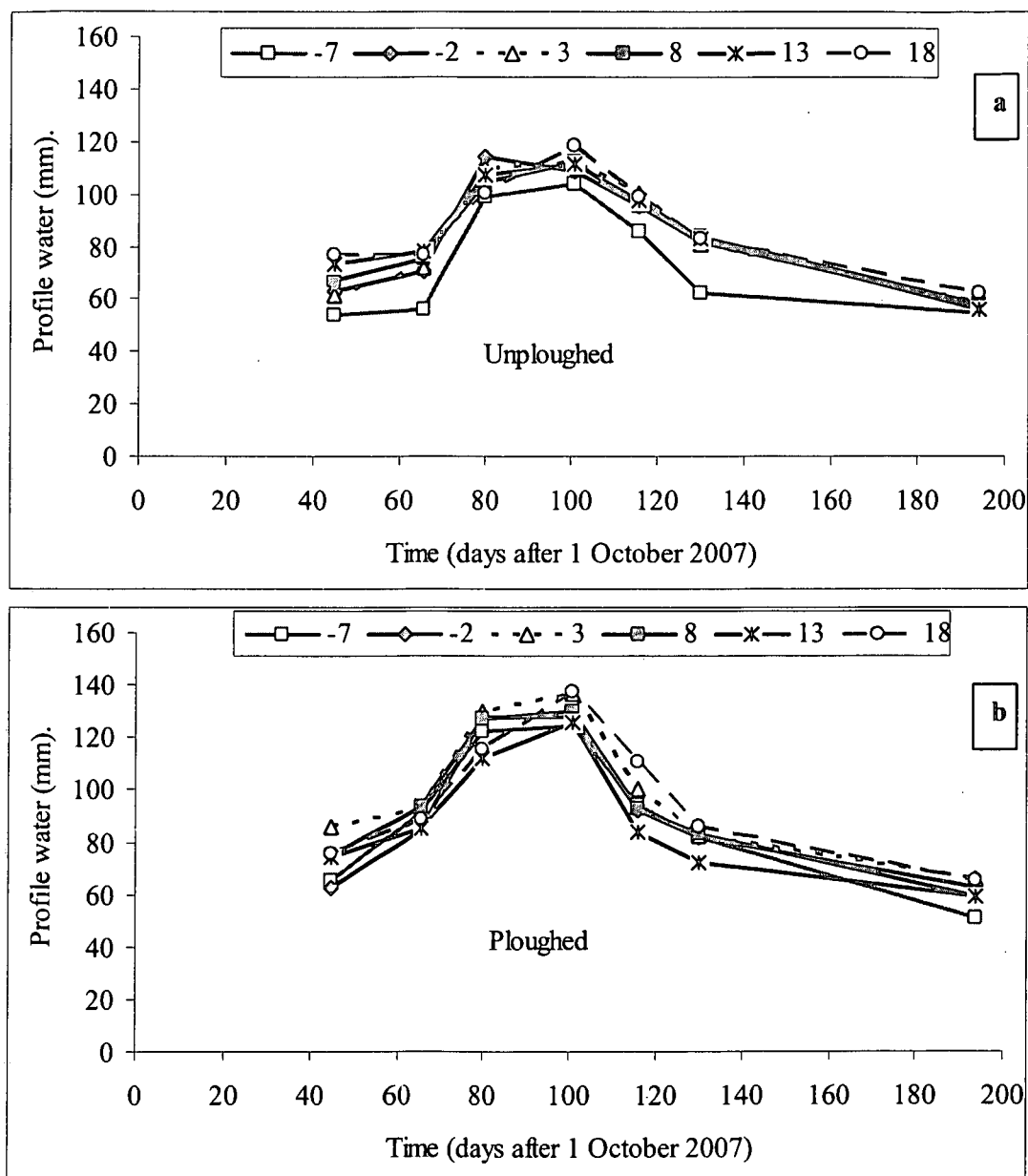


Figure 8.13. Profile soil water changes along unploughed (a) and ploughed (b) transects at farms with dead level contours and infiltration pits averaged across two farms (Dube and Siziba) during 2007/08 growing season

On 5 December (day 66), the ploughed transect had more ($P < 0.001$) soil water in the profile than the unploughed transect. The distance from the dead level contour and infiltration pit had no significant ($P = 0.084$) influence on soil water measured at each depth on 5 December (day 66) along either the unploughed or ploughed transects (Figs. 8.14 and 8.15). The wettest soil layers between 0.2 and 0.6 m depths were observed at 13 and 18 m from the contour along the unploughed transect on 5 December 2007. The driest soil layers were recorded at 7 m upslope. Lateral movement upslope was probably negligible. Along the ploughed transect the 0 – 0.15 m soil layer was the wettest at 3 m and driest at 8 m from the contour (Fig. 8.15).

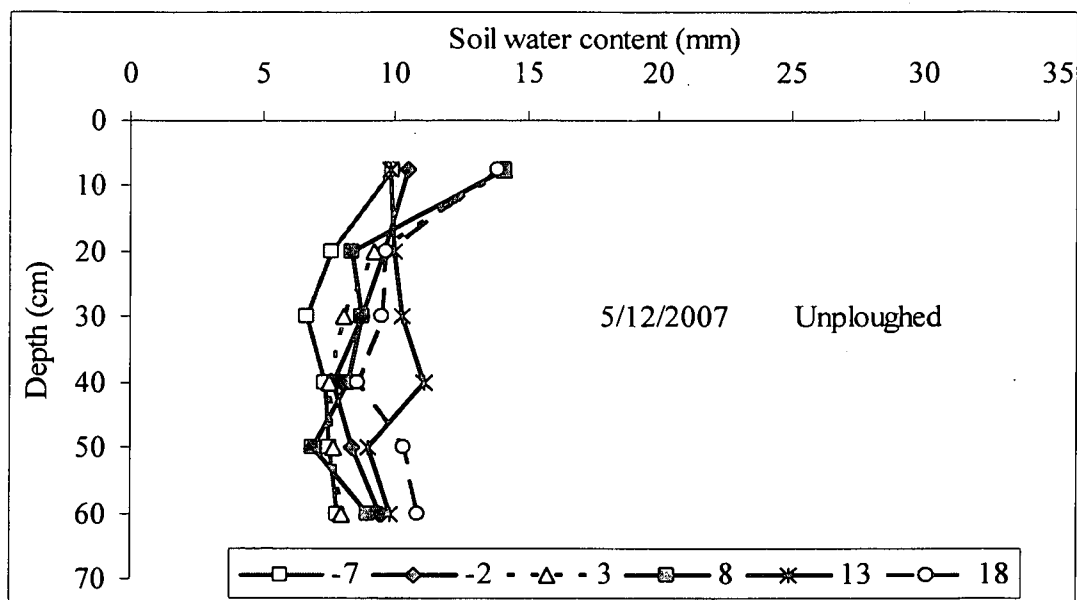


Figure 8.14. Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on driest day along unploughed transect during 2007/08 season

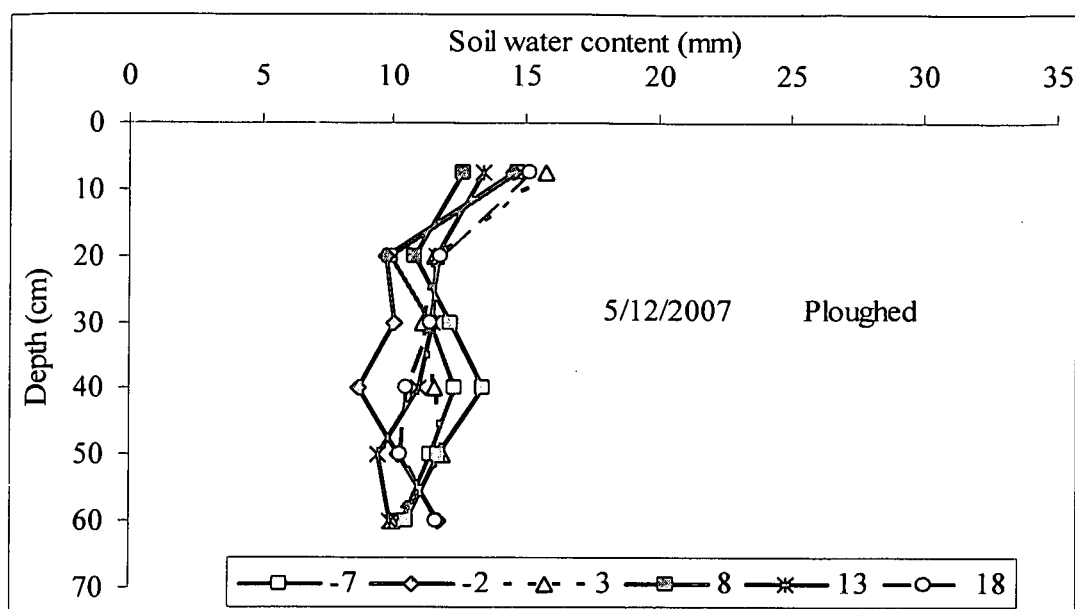


Figure 8.15. Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on driest day along ploughed transect during 2007/08 season

On 9 January (day 101) the soil profile along the ploughed transect had more ($P < 0.001$) soil water than the unploughed transect. This indicates that ploughing increased soil water content through collecting rainwater on in the soil surface depressions created during the tillage operation. The distance from the dead level contour and infiltration had no significant ($P = 0.485$) influence on soil water content measured at each soil depth along the unploughed transect. The 0 – 0.15 m soil layer had higher soil water content than the deeper layers along the unploughed and ploughed transects (Figs. 8.16a and 8.13b). Along the ploughed transect the wettest 0 – 0.15 m layer was at 18 m while the same layer was driest at 2 m upslope (Fig. 8.16b). Soil layers below 0.35 – 0.45 m were driest at 13 m from the dead level contour and infiltration pit.

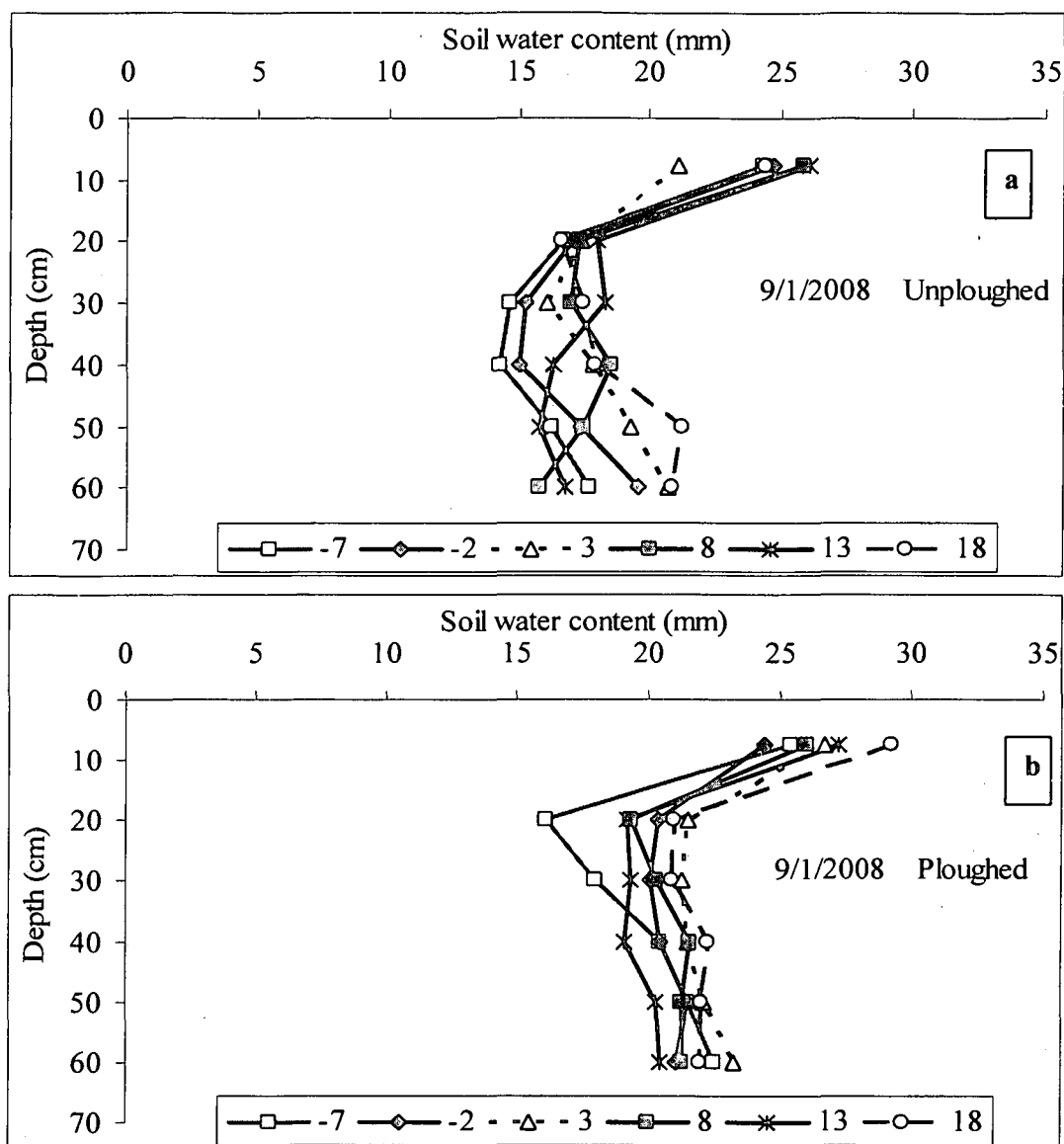


Figure 8.16. Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms (Dube and Siziba) on wettest day along unploughed (a) and ploughed (b) transects during 2007/08 season

8.4.5 Crop yields

The changes in soil water content (ΔS) from the first day of measurement (14 November 2007) to the last day (12 April 2008) are given in Tables 8.2 and 8.3. At farms with dead level contour only, soil water increased at 2, 3 and 8 m from the contour along the

ploughed transect (Table 8.2). In contrast soil water decreased at 3 and 8 m from the contour along the ploughed transect at farms with dead level contour and infiltration pits (Table 8.3). Crops planted along the ploughed transect extracted more soil water at farms with dead level contours and infiltration pits than at farms with dead level contours only. Evapotranspiration values were similar at all distances from the contour along the unploughed and ploughed transects during the 2007/08 season.

Table 8.2. Components of water balance averaged across two farms (Moyo and Ncube) at each distance along unploughed and ploughed transects the during 2007/08 season

Rainfall (mm)	Distance (m)	$\Delta SW_{\text{unploughed}}$ (mm)	$\Delta SW_{\text{ploughed}}$ (mm)	$ET_{\text{unploughed}}$ (mm)	ET_{ploughed} (mm)
247	-7	-1.1	-1.2	246	246
	-2	-7.9	5.2	239	252
	3	-15.0	2.0	232	249
	8	-3.9	3.9	243	251
	13	-2.4	-4.5	245	243
	18	-2.1	-1.3	245	246
	Mean	-3.9	0.7	242	248
	s.e.	2.7	1.5	2.2	1.4

Table 8.3. Components of the soil water balance averaged across two farms (Dube and Siziba) at each distance along unploughed and ploughed transects across dead level contours and infiltration pits during 2007/08 season

Rainfall (mm)	Distance (m)	$\Delta SW_{\text{unploughed}}$ (mm)	$\Delta SW_{\text{ploughed}}$ (mm)	$ET_{\text{unploughed}}$ (mm)	ET_{ploughed} (mm)
262	-7	0.2	-14.1	262	248
	-2	-6.0	-0.4	256	262
	3	-2.7	-20.0	259	242
	8	-9.1	-15.4	253	247
	13	-17.4	-14.9	245	247
	18	-14.6	-10.5	247	252
	Mean	-8.2	-12.5	254	250
	s.e.	2.8	2.7	2.7	2.8

Distance from dead level contour had no significant ($P > 0.05$) influence on maize and pearl millet yields observed at the end of 2007/08 season along the ploughed transect (Tables 8.4 and 8.5). There was no maize grain harvested during 2007/08 growing at the two farms because of drought (Table 8.5). The farms with dead level contours (Dube and Siziba) had higher pearl millet and maize yields than farms with dead level contour only (Moyo and Ncube) (Tables 8.4 and 8.5). Comparing the WUE of the four farms shows that farms with no infiltration pit had the lower WUE than farms with dead level contour and infiltration pit. The higher WUE at Dube and Siziba farms compared with Moyo and Ncube farms can be attributed to the higher yields achieved at the farms with dead level contours and infiltration pits as the ET values were quite similar (Tables 8.2 and 8.3). Generally yields and WUE observed at these farms were lower than reported elsewhere (Chapter 7; Ncube, 2007).

Table 8.4. Pearl millet and maize yields and water use efficiency between different positions from dead level contour averaged across two farms (Moyo and Ncube) along the ploughed transect at the end of the 2007/08 growing season

Position from contour	Crop	Grain yield (kg ha ⁻¹)	Biomass yield (kg ha ⁻¹)	WUE _{grain} (kg ha ⁻¹ mm ⁻¹)	WUE _{biomass} (kg ha ⁻¹ mm ⁻¹)
(-7) to (-2)	P. millet	160	865	0.6	3.5
3 to 8		95	845	0.4	3.4
8 to 13		150	1 005	0.6	4.1
13 to 18		240	1 265	1.0	5.2
Mean		161	995	0.7	4.0
s.e.		66	97	0.1	0.4
(-7) to (-2)	Maize	0	820	0	2.9
3 to 8		0	700	0	2.5
8 to 13		0	1 300	0	4.7
13 to 18		0	1 400	0	5.2
Mean		0	1 055	0	3.8
s.e.		0	173	0	0.7

Table 8.5. Pearl millet and maize yields and water use efficiency between different positions from dead level contour averaged across two farms (Dube and Siziba) with dead level contours and infiltration pits along the ploughed transect at the end of 2007/08 season

Position from contour (m)	Crop	Grain yield (kg ha ⁻¹)	Biomass yield (kg ha ⁻¹)	WUE _{grain} (kg ha ⁻¹ mm ⁻¹)	WUE _{biomass} (kg ha ⁻¹ mm ⁻¹)
(-7) to (-2)	P. millet	300	1 850	1.2	7.3
3 to 8		325	2 175	1.3	8.9
8 to 13		400	2 500	1.6	10.1
13 to 18		390	2 340	1.6	9.4
Mean		354	2 216	1.4	8.9
s.e.		73	138	0.1	0.6
(-7) to (-2)	Maize	0	1 400	-	6.7
3 to 8		0	1 100	-	5.8
8 to 13		0	1 200	-	6.2
13 to 18		0	900	-	4.5
Mean		0	1 150	-	5.8
s.e.		0	104.0	-	0.47

8.5 Conclusion

As expected the upward side of the dead level contour with or without infiltration pit was drier than downslope on most occasions when soil water was measured. The dead level contours with infiltration pits captured more rainwater following heavy rainfall events (more than 40 mm). After the contours and infiltration pits had filled with rainwater following rainfall events of 60 and 70 mm on the night of 8 to 9 January 2008, the wettest parts of the field were at -2 and 3 m from the contour. The lateral movement of soil water from the contour could also be detected at 8 m on the down slope at some farms.

The soil layers that benefited most from the rainwater captured by the dead level contours with/without infiltration pit were in the middle of the soil profile. Crops such as maize, sorghum, pearl millet and legumes commonly grown in semi-arid areas can access soil

water from these soil layers. The bulk of the active maize roots have been observed in the 0-0.8 m soil layer (Amato and Ritchie, 2002) although roots can reach 1.5 m deep depending on the soil type. For sorghum and pearl millet most of the roots are concentrated in 0 – 0.50 m soil layer (Zaongo *et al.*, 1997). Roots for grain legumes such as cowpea are also concentrated in the 0 – 0.50 m soil layer (Moroke *et al.*, 2005).

Given the crop-livestock systems of Gwanda district, it is probably worth exploring strip cropping of food and fodder crops on the downslope of the dead level contours and infiltration pits. Deep rooted fodder crops would probably benefit more from the soil water supply derived from dead level contours and infiltration pits. Combining structures such as dead level contours and infiltration pits with in-field rainwater harvesting techniques such as planting basins and tine ripping could be explored to assess if it will bring better returns to smallholder farmers where dead level contours and infiltration pits are being promoted and used.

CHAPTER 9a

Soil Water and Maize Yield Responses to Minimum Tillage and Mulching on Clayey and Sandy Soils in Semi-Arid Southern Zimbabwe

9a.1 Introduction

Water is one of the major factors limiting agricultural production in semi-arid areas of sub-Saharan Africa (Tsubo *et al.*, 2005). In the smallholder farming system of the semi-arid environments, rainfall is the only source of water for crop production. High in-season spatial and temporal rainfall variability makes crop production risky under the semi-arid conditions. Recurrent droughts and frequent mid-season dry spells are some of the major causes of reduced crop yields and total crop failures observed in smallholder cropping systems (Rockström *et al.*, 2003). Reducing total crop failure or substantial yield reductions due to droughts or mid-season dry spells remains a challenge for semi-arid crop production (Tabor, 1995).

The impact of low and poorly distributed rainfall on smallholder crop production can be reduced by practicing soil water management techniques. A wide range of techniques for soil water management have been developed for improved semi-arid smallholder crop production. Minimum tillage is one such technique that has been explored for improved and prolonged soil water supply during the cropping period. The minimum tillage techniques that have been developed include clean and mulch ripping, no-till tied ridging and zero tillage. Currently a planting basin tillage system is being widely promoted in the smallholder sector of the semi-arid districts of Zimbabwe (Twomlow *et al.*, 2008a; Chapter 7). These minimum tillage practices

simultaneously conserve soil and water resources, and increase or stabilise crop production.

The soil water and crop yield benefits derived from using minimum tillage under semi-arid conditions can be enhanced by using mulch cover in the cropping system. For the semi-arid areas mulching maybe a suitable agronomic practice for conserving soil water and controlling soil temperature regimes (Charkraborty *et al.*, 2008). The presence of crop residue mulch at the soil–atmosphere interface has a direct influence on infiltration of rainwater into the soil and evaporation from the soil (Erenstein, 2002). Mulch cover reduces surface runoff and holds rainwater at the soil surface thereby giving it more time to infiltrate into the soil. Soil biota increase in a mulched soil environment thereby improving nutrient cycling and organic matter build up over a period of several years (Holland, 2004).

The effect of the basin and ripper systems, and mulching on soil water dynamics and crop yields have not been quantified under the semi-arid conditions of southern Zimbabwe. This trial was designed to assess the soil water and maize yield benefits derived from practicing ripper and basin tillage systems combined with mulching under the semi-arid conditions of southern Zimbabwe. The chapter reports the findings from two seasons of experimentation on a sandy soil at Lucydale experimental site and four seasons using a clay soil at Matopos Research Station.

9a.2 Objectives

This study uses on-station field experiments:

- (1) to determine soil water responses to conventional ploughing, ripper and basin tillage systems, and mulching;
- (2) to determine maize (*Zea mays* L.) yield responses to conventional, ripper and basin tillage systems, and mulching; and
- (3) to identify the optimum rates of mulch application for low potential areas of southern Zimbabwe.

9a.3 Materials and Methods

9a.3.1 Experimental set up

The experiment was set up with a factorial treatment structure consisting of three tillage methods (conventional ploughing, ripping and planting basins) and seven rates of mulch cover (0, 0.5, 1, 2, 4, 8 and 10 tha^{-1}). Plots at Lucydale and Matopos were initially pegged out in October 2004 and then maintained in subsequent seasons. The treatments were arranged in a split-plot design with three replications at each field location. The main plot factor was tillage (63 m $\times$ 6 m) and seven mulch levels were randomly allocated in sub-plots (8 m $\times$ 6 m) on each tillage treatment. Each plot was separated by a 1 m pathway to avoid movement of residue from one plot to the next when tillage was undertaken. At Matopos research site a new field was established for the experiment in 2005/06 as cowpea was planted on the 2004/05 field as part of a rotation (Table 9a.1). Unfortunately, due to logistical problems it was not possible to establish a new field at Lucydale in 2005/06. Residues at the location were not enough to make fresh mulch applications. As a consequence in 2005/06 the residual effect of the previous season's mulch levels was assessed.

Digging of planting basins and ripping were carried out after applying mulch cover in August/September of each year, with the exception of the first year when all operations were carried out in October. Planting basins were dug at 0.9 m × 0.6 m spacing using a hand hoe and each basin measured 0.15 m (length) × 0.15 m (width) × 0.15 m (depth). Rip lines were opened at 0.9 m inter-row spacing using a commercially available ripper tine (ZimPlow) attached to the beam of a donkey-drawn mouldboard plough. The ripping depth achieved on both soils, with a single pass of the implement, varied between 0.15 and 0.18 m. Cattle manure (40 % organic carbon, 0.43 % N, 0.21 % P) was applied in October each year at a rate of 3 t ha⁻¹ in all plots as basal soil fertility amendment. Manure was placed in the planting basins in the basin system, dribbled along the rip line in the ripper system and broadcast in the conventional system. Conventional ploughing was done soon after the first effective rain (30 to 50 mm) in December each year using a donkey-drawn VS100 mouldboard plough. Planting furrows were then opened by donkey-drawn conventional plough at inter-row spacing of 0.9 m in the conventional system. During the ploughing process most of the crop residue applied as mulch was partially incorporated into the soil.

Table 9a.1. Experimental fields used and crops grown in each field from 2004/05 to 2007/08 seasons at Matopos Research Station

Season	Experimental field	Crops grown	Crop phase
2004/05	1	Maize	1
2005/06	1	Cowpea	1
2005/06	2	Maize	2
2006/07	1	Sorghum	1
2006/07	2	Cowpea	2
2006/07	3	Maize	3
2007/08	1	Maize	4
2007/08	2	Maize	4
2007/08	3	Maize	4
2007/08	4	Maize	4

9a.3.2 Experimental management

Planting on both soils was done between November and December in each season depending on the onset of the rains. At Matopos a hybrid maize variety, SC403, was planted in both seasons whereas at Lucydale an open pollinated variety, ZM421, was planted in 2004/05 season and SC403 in 2005/06. An open pollinated variety had to be planted at Lucydale in 2004/05 season in order to avoid contamination of breeding trials that were established near our experimental field. Plant spacing was 0.9 m × 0.6 m with three kernels per station for planting basins. In-row spacing was 0.3 m with two kernels per station for the ripping and conventional tillage treatments. Plants were thinned two weeks after crop emergence to two per basin in planting basin and one plant per station in the ripping and conventional tillage treatments. Ammonium nitrate (34.5% N) was applied to all plots at 20 kgNha⁻¹ as topdressing when the maize had reached the 6 leaf stage. Weeds were controlled by hand hoe as required in all seasons at each site.

9a.3.3 Data collection and analysis

In every season plant counts in each treatment was done two weeks after crop emergence. At harvest grain and stover (above-ground biomass minus grain) yields were estimated from a net plot consisting of five middle rows with a running length of 6 m. The weight of cobs and stover from the net plot of each treatment were determined in the field before taking sub-samples for moisture correction. Grain and stover samples were dried at 60°C for 48 hours for moisture adjustment. The maize shelling percentage was determined for each treatment so as to be able to convert cob weight into grain and core weights. Grain weight was converted to a per hectare basis at 12.5% moisture content as final grain yield

In the 2004/05 and 2005/06 seasons gravimetric soil water was determined by collecting soil samples fortnightly between planting basins, along riplines and rows in the basin, ripper and conventional tillage systems, respectively. Soil samples were collected at 0.15 m depth interval up to a maximum depth of 0.6 m. The soils were weighed before oven drying them at 105°C for 48 hours for determining gravimetric water content. Gravimetric water content for each soil layer was calculated using the procedure outlined by Anderson and Ingram (1993). Gravimetric water content was converted to volumetric water content for each respective depth using the measured bulk density for each soil layer. Soil water content in millimetres was determined by multiplying volumetric water content by thickness of each layer from which soil water was measured. In 2006/07 and 2007/08 growing seasons soil water was measured weekly at 0.1 m depth interval using a microgopher type capacitance probe.

Statistical analysis of maize crop data was done using split plot design with tillage as main plot factor and mulch application rate as subplot factor. Regression analysis was conducted to assess the relationship between mulch treatments and measured parameters of the maize crop. Soil water data were analyzed using unbalanced treatment design of ANOVA because of soil depth differences of access tubes installed for soil water monitoring. All statistical analyses were conducted using Genstat Discovery Edition 3 (www.vsni.co.uk). The least significant difference (Lsd) at 5 % significance level was used to compare treatment means.

9a.4 Results and Discussion

9a.4.1 Site characteristics

Table 9a.2 summarises the major soil physical and chemical characteristics at the two experimental field sites, based on detailed soil analyses undertaken by Moyo in 2001. The effective soil depth of the clay loam at Matopos was 1.3 m, compared to 0.9 m for the sandy soil at Lucydale. Irrespective of soil texture observed at each site, clay content increases with depth (Table 9a.2). The slopes were 0.5 - 1 % at Matopos and 3 % for Lucydale (Moyo, 2001).

Table 9a.2. Physical and chemical characteristics of Matopos and Lucydale soils, after Moyo (2001)

Soil property	Matopos				Lucydale			
Classification	Chromic-Leptic Cambisol				Eutric Arenosol			
Depth (cm)	0-6	6-16	16-40	40-60	0-12	12-24	24-35	35-57
Clay (%)	41	38	47	52	4	5	6	10
Silt (%)	20	23	17	17	4	5	4	3
Sand (%)	38	39	36	31	91	91	99	87
Gravel (%)	-	-	-	-	5	7	8	17
pH (CaCl ₂)	7.5	7.6	7.7	7.8	5.0	4.9	4.8	5.5
O.C. (%)	0.46	0.80	0.37	0.48	0.00	0.00	0.04	0.00
Ca (Cmol _c kg ⁻¹)	40.2	40.9	32.3	33.4	1.2	0.80	0.70	3.1
Mg (Cmol _c kg ⁻¹)	14.8	15.4	16.6	19.7	0.40	1.00	0.70	2.2
K (Cmol _c kg ⁻¹)	1.98	1.77	1.64	1.67	0.02	0.03	0.03	0.04

9a.4.2 Lucydale site

9a.4.2.1 Seasonal rainfall

Total rainfall recorded during 2004/05 growing season at Lucydale was 320 mm, which was 56 % of the long term average rainfall for the Matopos area (Chapter 4). The October-December and January-March periods recorded 160 mm each. The rainfall received during October-December and January-March periods was less than

the 69 year average for the first and second halves of the growing season (Chapter 4). The 69 year October-December and January-March rainfall averages are 248 and 291 mm respectively. There was a 31-day dry spell that stretched from 26 January (day 118) to 25 February 2005 (day 148) (Fig. 9a.1). This 31-day dry spell started 43 days after planting of the maize crop (Table 9a.3). In the 2005/06 season rainfall was well distributed during the maize growing period and the total rainfall amount recorded was 787 mm. The October-December and January-March periods recorded 393 and 394 mm of rain during 2005/06 season and these were higher than the 69 year average for the first and second halves of the season for Matopos (Chapter 4).

In both 2004/05 and 2005/06 seasons, the soil profile at Lucydale had been recharged following rainfall events that occurred before the planting dates. In the 2004/05 season 104 mm of rain was accumulated between 1 December (day 62) and 14 December 2004 (day 75). The soil profile was even wetter in the 2005/06 season than 2004/05 after 288 mm of rain was received between 1 December and 14 December 2005. In the 2004/05 season planting was followed by an 8 day dry spell while in the 2005/06 a 30 mm rainfall event was recorded two days after planting. This allowed better maize crop establishment in the 2005/06 season than 2004/05 season (see later in Tables 9a.4 and 9a.5).

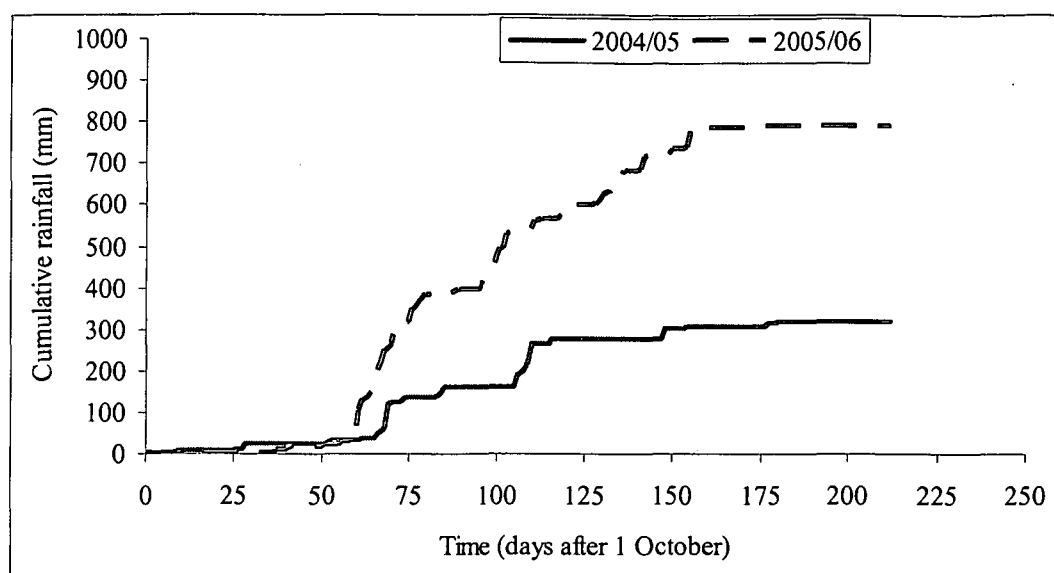


Figure 9a.1. Daily rainfall distribution at Lucydale experimental site during 2004/05 and 2005/06 growing seasons

Table 9a.3. Characteristics of the 2004/05 and 2005/06 growing seasons at Lucydale experimental site

Season	2004/05	2005/06
* Start	9/12/2004	1/12/2005
* End	26/2/2005	4/3/2006
Number of rainy days	18	40
Maximum 24 hour rainfall (mm)	55	75
Total seasonal rainfall (mm)	320	787
Planting date	14/12/2004	14/12/2005

* The criteria for start and end of the growing season and rainy day have been defined in Chapter 4.

9a.4.2.2 Soil water regimes

The tillage system had no significant ($P = 0.231$) influence on soil water content measured in the 0 – 0.30 m soil profile during the 2004/05 season. However, soil water content increased ($P < 0.005$) with an increase in mulch cover in the 0.30 m layer of this sandy soil in 2004/05 (Fig. 9a.2). In the conventional and ripper systems, soil water content was significantly higher at 2 and 4 tha^{-1} mulch cover than the basin system. Further increase in mulch cover over and above 4 tha^{-1} did not give additional benefits in soil water content under any of the three tillage treatments.

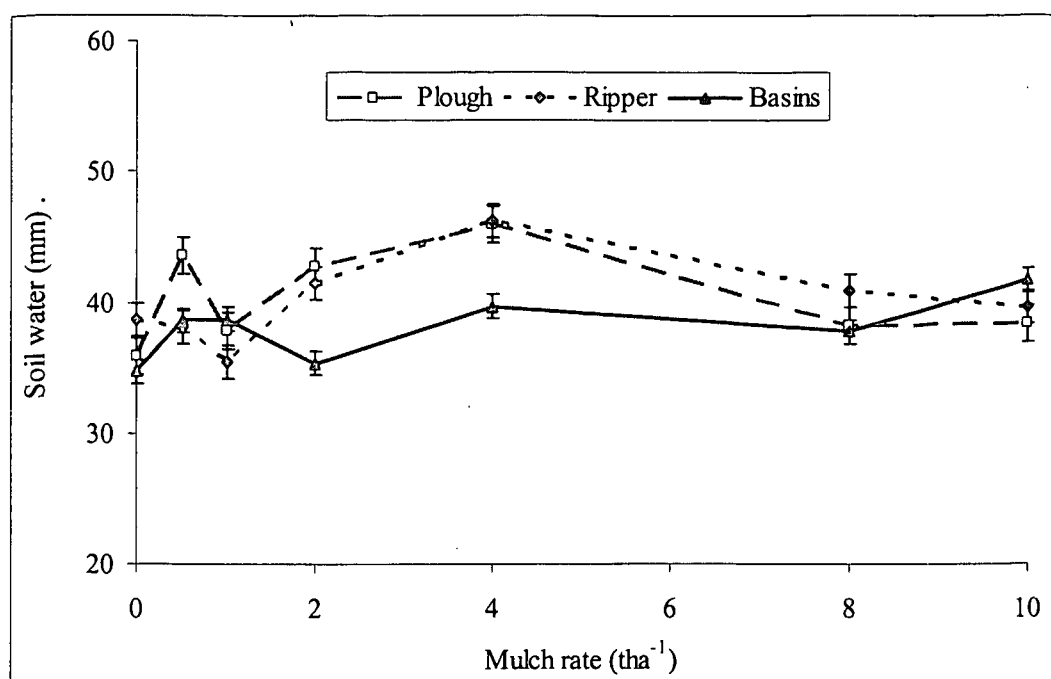


Figure 9a.2. Average seasonal soil water content in the 0–0.30 m profile at Lucydale during 2004/05 cropping season. Bars indicate standard error

In the 2005/06 season neither tillage system nor the residual effects of the previous season's mulch treatments had any significant ($P > 0.05$) influence on soil water content measured in the 0 – 0.3 m profile (Fig. 9a.3). Soil water content measured on 7 March (day 158) was significantly ($P < 0.001$) higher than soil water content observed on other sampling dates. This was attributed to a 45 mm rainfall event that was received on 4 March 2006 (day 155). However, the water content was similar for all tillage treatments with 69, 70 and 72 mm being recorded in the 0 – 0.60 m profile under conventional, ripper and planting basin tillage systems respectively. This represented a 38, 24 and 42 % increase in profile soil water content from the previous measurement in the CP, ripper and basin systems. This water was just as quickly lost as the values measured on day 173 (23 March) was about 28 mm.

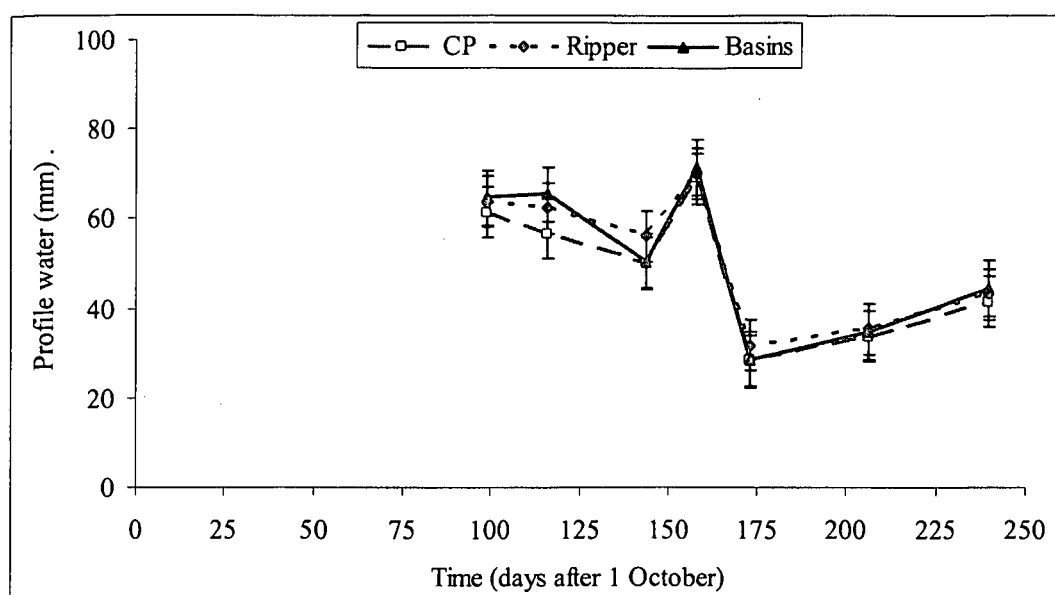


Figure 9a.3. Soil water content in the 0–0.60 m profile at Lucydale during 2005/06 cropping season. Bars indicate standard error

9a.4.2.3 Maize crop performance

The basin tillage system had significantly ($P = 0.002$) higher number of plants than conventional and ripper tillage systems during 2004/05 growing season (Table 9a.4). Planting basin system had an average of 2.8 plants per m^2 compared with 1.3 and 1.2 plants per m^2 for the conventional and ripper tillage systems. Planting basins collect rainwater and gives it more time to infiltrate into the soil. This leaves the soil in the basin moist for much longer than rip furrows and conventional ploughing. The seed planted in a basin has access to soil water for a slightly longer period compared to ripper and conventional systems. The better maize crop establishment observed in the basin system at Lucydale has also been reported on farmers' fields in semi-arid districts of Zimbabwe where conservation farming is being promoted (Chapter 7). Maize grain production was not significantly influenced ($P > 0.05$) by the tillage system during the 2004/05 growing season at Lucydale. The maize yields were lowest at 466 kg ha^{-1} for the conventional, with 619 kg ha^{-1} in the ripper and $1\,069 \text{ kg ha}^{-1}$ for

basin tillage systems. Maize harvest index was not significantly ($P > 0.05$) influenced by the tillage system used. Mulching had no significant ($P > 0.05$) effect on maize grain and stover production, harvest index and plant stand during the 2004/05 growing season. One would have expected the mulching benefits on maize yields in 2004/05 given the dry spells recorded between January and February 2005 when the maize crop was in its reproductive stages. Although soil water increased with increase in mulch cover (Fig. 9a.2), this soil water advantage was not translated into grain yield on a sandy soil. Probably soil fertility constraints became more limiting to crop growth than soil water availability in this particular season on a sandy soil.

Table 9a.4 summarises maize yield responses to the two-way tillage and mulch interaction during the 2004/05 season. Under the conventional ploughing system grain yield decreased with increase in mulch treatment from 1 to 8 tha^{-1} . Under the ripper system, 10 tha^{-1} mulch treatment gave 514 kgha^{-1} more grain than 1 tha^{-1} which was the lowest yielding mulch treatment. In the planting basin tillage system 2 tha^{-1} mulch treatment gave highest grain yield of 1 470 kgha^{-1} with 10 tha^{-1} achieving 711 kgha^{-1} . The lowest ($P = 0.010$) harvest index were recorded at 8 tha^{-1} mulch treatment in the conventional ploughing, at zero mulch in the ripper and at 10 tha^{-1} mulch in the planting basin tillage systems. Maize stover production and plant stand were not significantly affected by the tillage and mulch rate interaction on the Lucydale sandy soil.

Table 9a.4. First year effects of tillage and mulch treatments on maize crop performance at Lucydale experimental site in 2004/05 growing season

Tillage	Mulch rate (tha ⁻¹)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index	Plant stand (m ⁻²)
Plough	0	693	568	0.47	1.6
	0.5	269	654	0.31	1.3
	1	503	568	0.42	1.2
	2	423	617	0.37	1.4
	4	406	642	0.35	1.1
	8	213	592	0.26	1.1
	10	754	889	0.40	1.5
	Mean	466	647	0.37	1.3
Ripper	0	415	803	0.31	1.4
	0.5	781	913	0.43	1.5
	1	323	482	0.37	0.9
	2	812	716	0.45	1.4
	4	542	815	0.32	1.1
	8	624	568	0.46	1.0
	10	837	568	0.45	1.3
	Mean	619	695	0.40	1.2
Basins	0	1 259	1 037	0.51	2.8
	0.5	949	988	0.42	2.8
	1	972	1 062	0.45	2.7
	2	1 470	1 173	0.50	2.9
	4	1 276	1 197	0.47	3.0
	8	1 026	753	0.52	2.7
	10	711	1 161	0.36	2.7
	Mean	1094	1053	0.46	2.8
	Lsd _{0.05} (tillage)	512	183	0.21	0.49
	Lsd _{0.05} (mulch)	284	338	0.07	0.41
	Lsd _{0.05} (tillage x mulch interaction)	607	557	0.21	0.74
	CV (%)	40	44	19	24

In the 2005/06 season, maize crop stand was significantly ($P < 0.001$) influenced by the tillage system used. The ripper system had more plants per m² than conventional and basin tillage systems (Table 9a.5). In the 2005/06 season soil water was not a limiting factor for maize crop establishment and growth in each tillage system compared with the 2004/05 season. Maize grain and stover production were not significantly ($P > 0.05$) influenced by the tillage system and residual mulch cover during 2005/06 season. Most the maize residue applied in 2004/05 season as mulch

had rotten away by the beginning of the 2005/06 season. Only the plots that had received 8 and 10 tha^{-1} in 2004/05 season had some maize residue left by the beginning of 2005/06 season. Maize residues decompose rapidly especially during the summer period when temperature and soil water conditions are conducive (Nhamo, 2007). Nhamo (2007), using the litter bag technique, observed a 45 – 50 % weight loss of maize residues applied as mulch during summer.

Table 9a.5. Second year effects of tillage and residual mulch treatments on maize crop performance at Lucydale experimental site in 2005/06 growing season

Tillage	Mulch rate (tha^{-1})	Grain yield (kgha^{-1})	Stover yield (kgha^{-1})	Harvest index	Plant stand (m^{-2})
Plough	0	1 796	2 533	0.35	2.0
	0.5	2 714	2 610	0.45	1.9
	1	1 880	2 933	0.35	1.9
	2	1 834	3 082	0.32	2.3
	4	2 961	3 022	0.46	1.7
	8	1 785	4 033	0.30	1.9
	10	2 231	2 832	0.41	1.6
	Mean	1 910	3 006	0.38	1.9
Ripper	0	2 851	3 245	0.43	3.3
	0.5	3 843	4 652	0.44	3.3
	1	2 606	3 096	0.45	3.1
	2	3 654	3 911	0.45	3.1
	4	3 122	3 259	0.45	2.3
	8	2 626	3 837	0.39	3.2
	10	2 263	2 356	0.47	3.3
	Mean	2 995	3 479	0.44	3.1
Basins	0	1 505	2 321	0.42	2.6
	0.5	2 596	3 210	0.43	2.1
	1	3 226	3 975	0.40	2.1
	2	2 604	4 420	0.36	2.1
	4	2 425	2 827	0.43	2.0
	8	1 410	2 049	0.39	2.1
	10	1 665	2 185	0.40	2.0
	Mean	2 204	2 998	0.40	2.1
Lsd _{0.05} (tillage)		2 233	3 129	0.13	0.31
Lsd _{0.05} (mulch)		1 134	1 394	0.07	0.43
CV (%)		48	46	17	19

9a.4.3 Matopos site

9a.4.3.1 Seasonal rainfall

Total seasonal rainfall for 2004/05 was 359 mm at Matopos (Table 9a.6) and this was 61 % of the long term average rainfall reported by Ncube (2007) for the site. The October-December and January-March periods received 199 and 160 mm of rain during the 2004/05 season. These rainfall amounts for the both first and second halves of the season were below the long term averages for the October-December and January-March periods (Chapter 4). During the 2004/05 cropping period rainfall distribution was poor between mid-January and 1 March (day 153) (Figs. 9a.4). This coincided with end of the vegetative and start of reproductive stages of the hybrid maize variety grown at Matopos. As observed at Lucydale, rainfall was also well distributed at Matopos experimental site during the 2005/06 growing season with a total of 832 mm being recorded for that season (Table 9a.6). The first and second halves of the season received 412 and 420 mm of rain and these were 66 and 44 % more than the long term average for these periods of the growing season (Chapter 4). The 2005/06 growing season had the highest number of wet days and largest daily rainfall event compared to the other three seasons (Table 9a.6). There was more variation with the end of growing season than its start during the four seasons of experimentation.

Table 9a.6. Characteristics of the 2004/05, 2005/06, 2006/07 and 2007/08 growing seasons at Matopos experimental site

Season	2004/05	2005/06	2006/07	2007/08	Long term mean
Start	8/12/2004	30/11/2005	17/11/2006	23/11/2007	2/12
End	27/2/2005	19/3/2006	4/4/2007	26/1/2008	29/3
Number of rainy days	18	41	25	23	22
Maximum 24 hour rainfall (mm)	55	80	52 18/11/2006	46 17/12/2007 25/1/2008	
Total seasonal rainfall (mm)	359	832	465	364	573
Planting date	13/12/2004	13/12/2005	21/11/2006 for ripper and basin; 8/12/2007 for plough	12/12/2007	

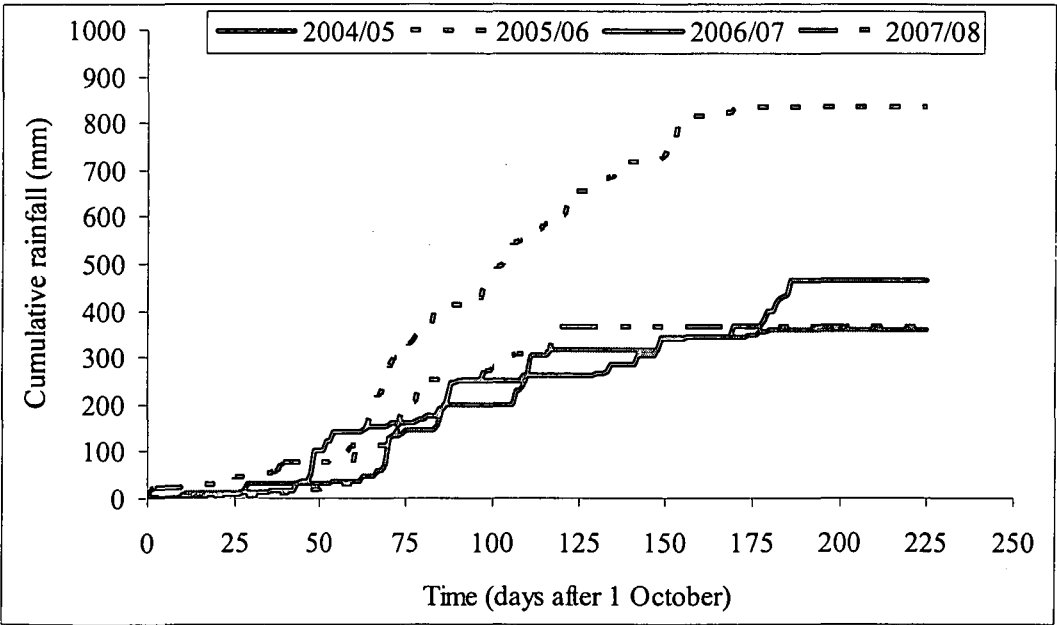


Figure 9a.4. Cumulative rainfall distribution at Matopos experimental site during 2004/05, 2005/06, 2006/07 and 2007/08 growing seasons

Rainfall was poorly distributed during 2006/07 growing season and 465 mm was received between October 2006 and April 2007 (Table 6). The first and second halves of the growing season received 252 and 169 mm during 2006/07. The October-December period received slightly more than the 69 year average rainfall for Matopos

while the second half received 42 % less than the 69 year average rainfall (Chapter 4). In January 2007 only 12 mm of rainfall was recorded on 17 January (day 109). Following a 16 day dry spell was experienced between 1 January 2007 and 16 January 2007. This dry spell was immediately followed by a 20 day dry spell which started on 18 January 2007 and ended on 6 February 2007. There is a 5-11 % chance of getting 21 day dry spells in January at Matopos (Chapter 4). The first dry spell started 41 days after planting in the ripper and basin tillage systems and 24 days after planting in the conventional system (Table 9a.6) so the plants were still small. The next rainfall event after 17 January 2007 was 3.8 mm received on 7 February 2007 (day 130) and this was followed by a 5 mm rainfall event that occurred on 10 February 2007 (day 133). These would have little effect on crop growth as they are less than 10 mm. The highest daily rainfall event was 52 mm (Table 9a.6) and was received on 18 November 2006.

Total seasonal rainfall for 2007/08 growing season was 364 mm which was 38 % less than the long term average rainfall for Matopos. The October-December and January-March periods received 250 and 114 mm of rain respectively. The first half received slightly more than the 69 year average rainfall while the January-March period recorded 62 % less rainfall than the 69 year average (Chapter 4). The last rainfall event of season was 46 mm recorded on 25 January 2008 (day 117) but does not set a new record as previous extreme was on 13 December (Chapter 4). The maize crop had to rely on stored soil water between 25 January 2008 (day 117) and the physiological maturity stage of the crop. The highest daily rainfall was 46 mm received on 17 December 2007 (day 78) and also on 25 January 2008 (day 117) (Table 9a.6).

As observed at the Lucydale site in the 2004/05 and 2005/06 seasons, the soil profile at Matopos was adequately recharged prior to planting. In the 2004/05 season 75 mm of rain were accumulated in five days before the planting date. In the 2005/06 season 81 mm of rain were accumulated in five days before the planting date. In the 2006/07 season the ripper and basin systems were planted earlier than conventional system. It was too wet to plough the red clay soil after receiving 68 mm of rain five days prior to 21 November 2006 as the soil profile was recharged by a 52 mm rainfall event received on 18 November 2006 (day 49). In the 2007/08 season, planting was done after accumulating 39 mm of rain four days prior to planting.

Generally the January-March half of the season was drier than the October-December period during 2004/05, 2006/07 and 2007/08 growing seasons. This observation is at odds with earlier results obtained in Chapter 4 which show that in the long term the January-March period was wetter than the October-December period. The 2004/05, 2006/07 and 2007/08 seasons were probably some of the seasons with below average rainfall that occur in semi-arid areas. The abrupt end of the 2007/08 growing season on 25 January 2008 had a large detrimental impact on maize yields achieved under all the different tillage systems and mulching treatments showing that in some seasons it is not possible to prevent crop failure. The unpredictability of start and end of the growing seasons is one of the major challenges in rainfed cropping in semi-arid areas (Dennett, 1987). The dry spells of more than two weeks observed at Matopos during the seasons with below average rainfall have also been reported in other semi-arid environments of Africa (Sivakumar, 1992; Rockström *et al.*, 2003).

9a.4.3.2 Soil water regimes

Figure 9a.5 gives the soil water content in the 0 – 0.30 m soil profile at Matopos during 2004/05 season. Despite the below-average rainfall, the three tillage methods had no significant ($P = 0.866$) influence on the average soil water content observed in the top 0.30 m. There was a general increase in average seasonal soil water content with increasing mulch rate from 0 to 4 t ha^{-1} . A mulch rate of 4 t ha^{-1} appears to be a threshold point on this soil for the season, with a significant ($P < 0.001$) increase in soil water content, compared to the lower mulch rates. The low soil water content observed at 1 t ha^{-1} mulch cover in the ripper system can probably be attributed to human error during the processing of soil samples for gravimetric water determination.

In the 2005/06 season neither tillage nor mulching treatments had any significant ($P > 0.05$) influence on soil water content measured in the top 0.60 m depth during this wetter-than-average season. The basin system started with marginally higher soil water content in the top 0.60 m soil depth (Fig. 9a.6), suggesting some initial water harvesting. However, soil water content in the top 0.60 m of the profile gradually declined as the season progressed (Fig. 9a.6).

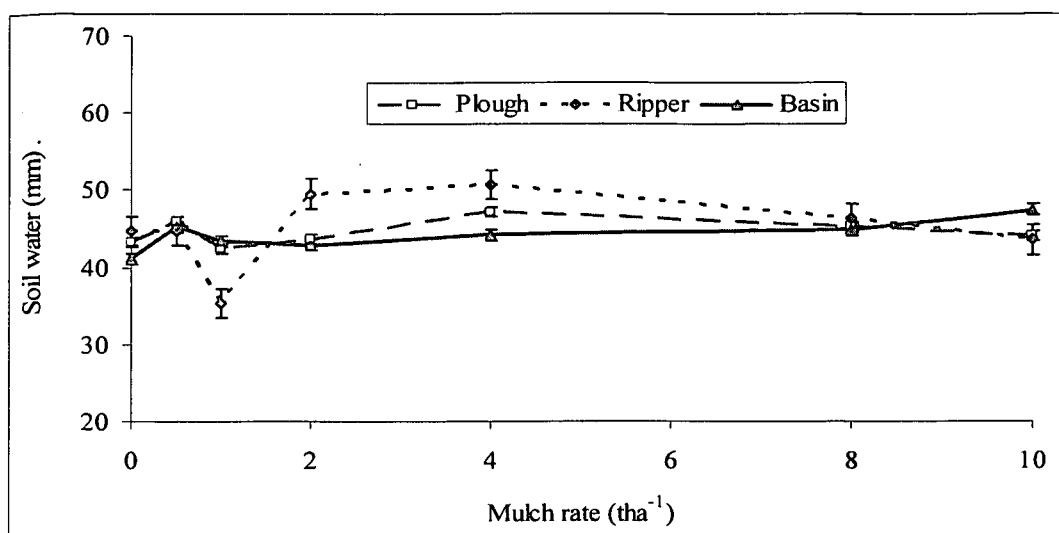


Figure 9a.5. Average seasonal soil water content in the 0 – 0.30 m profile under three tillage systems and mulching treatments at Matopos during 2004/05 season. Bars indicate standard error of means

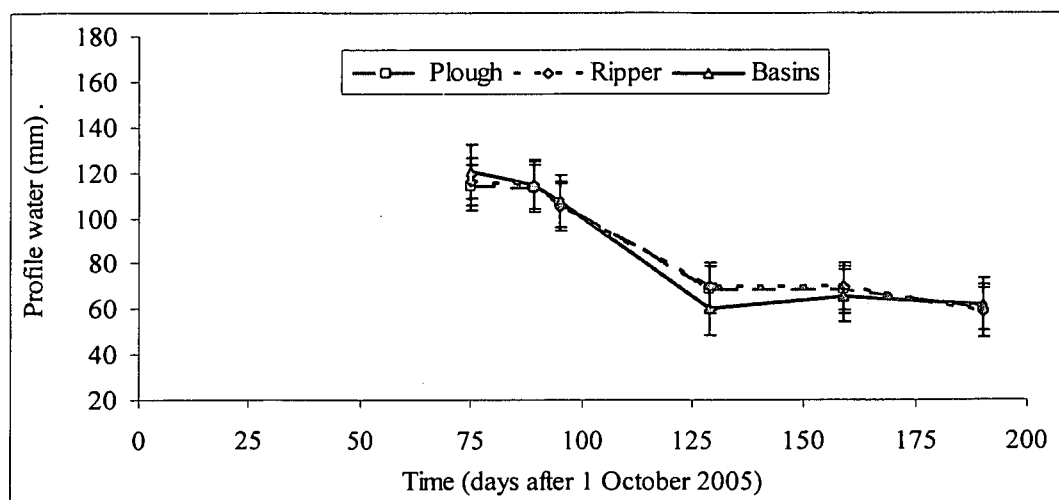


Figure 9a.6. Soil water content in the 0 – 0.30 m profile at Matopos during 2005/06 cropping season. Bars indicate standard error

In the 2006/07 season, profile soil water dynamics were quite similar in conventional, ripper and basin tillage systems (Figs. 9a.7). Day 142 (20 February 2007) had the lowest profile water content during the growing season as the small showers (18 mm in total) had no effect after the long dry spells. On that day conventional tillage system had 114 mm at 0 tha⁻¹ mulch, 100 mm at 2 tha⁻¹, 109 mm at 4 tha⁻¹ and 99 mm

at 10 tha^{-1} mulch treatment. The ripper system had 97 mm for 0, 2 and 4 tha^{-1} while 10 tha^{-1} mulch treatment had 104 mm. Planting basins had 100, 108, 87 and 113 mm of soil water at 0, 2, 4 and 10 tha^{-1} mulch treatments. The higher profile water content at 10 tha^{-1} mulch cover in the basin and ripper systems is attributed to mulching being able to reduce soil evaporation and hence conserve soil water.

Changes in soil water content in the top four soil layers followed a similar pattern in the three tillage systems (Fig. 9a.8). The 0 – 0.15 m soil layer responded to wetting and drying cycles more dramatically than the other layers. The 0.15 – 0.25 m layer consistently held the lowest amount of soil water throughout the growing season in all tillage systems. The low soil water content in the 0.15 – 0.25 m soil layer is attributed to root extraction by the maize crop. Studies conducted by Vogel (1992) and Chikowo *et al.* (2004) in the relatively wetter northern Zimbabwe indicated that a large proportion of maize roots occur within the 0 – 0.2 m plough layer.

In the 2007/08 season soil water content in the 0 – 0.85 m profile responded to rainfall events in all three tillage systems throughout the growing season (Fig. 9a.9). In the conventional system, 10 tha^{-1} mulch treatment had slightly more soil water than other mulch treatments particularly from day 85 (24 December) up to the end of season. In the ripper system there was more soil water under 10 tha^{-1} treatment than the other mulch treatments following rainfall events of December 2007 and January 2008. In the basin system 10 tha^{-1} mulch treatment had more ($P = 0.017$) soil water throughout the growing season particularly during extended dry period after day 150 (27 February) to the end of the season. As observed in other seasons at the Matopos site, the 0.15 – 0.25 m layer had the lowest water content in all tillage systems throughout

2007/08 growing season (Fig. 9a.10). The top soil layer (0 – 0.15 m) also showed significant responses to wetting and drying cycles. The deepest layer (0.35 – 0.45 m) had the highest soil water content in the second half of the growing season.

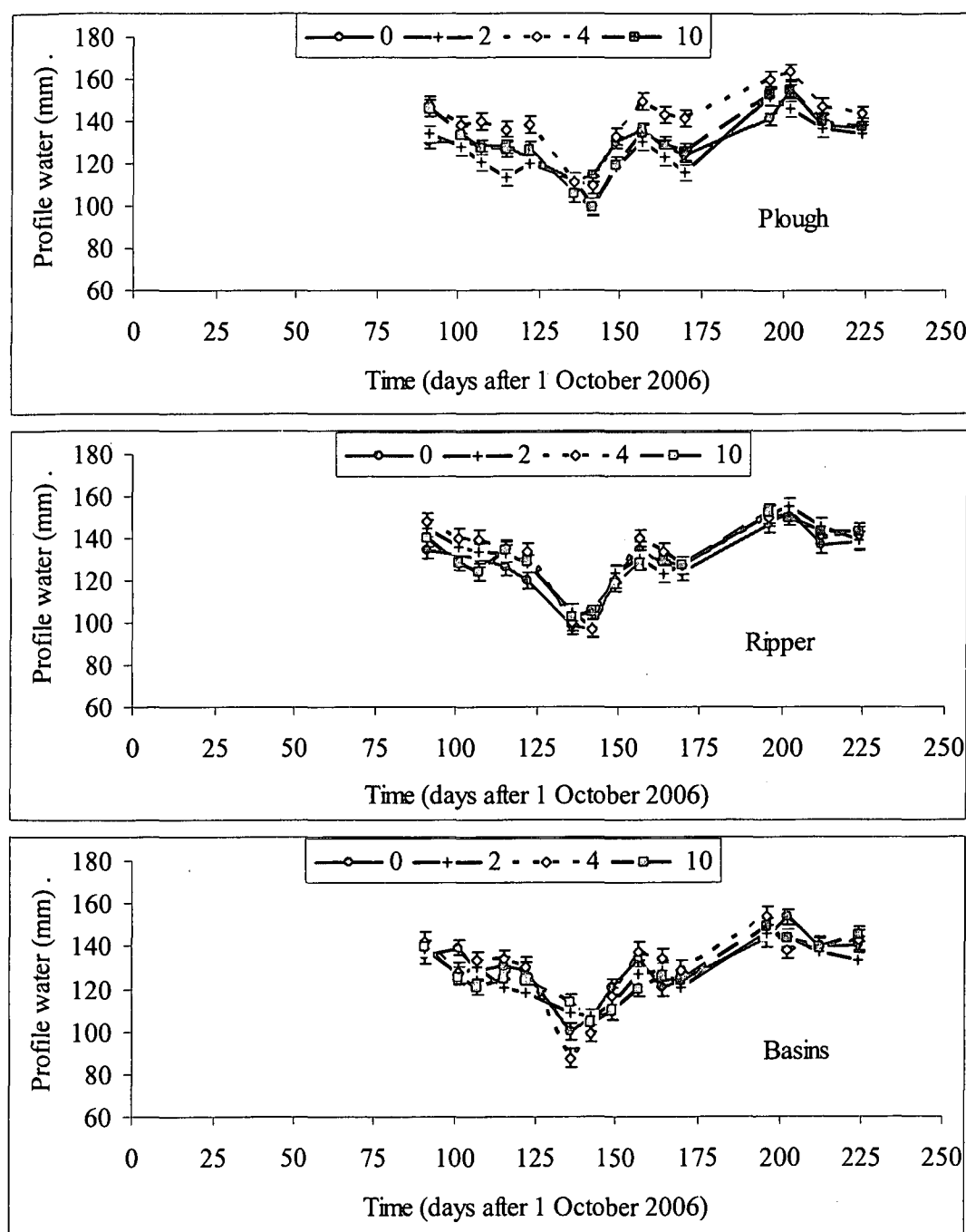


Figure 9a.7. Profile soil water changes in the conventional ploughing, ripper and basin system and four mulch treatments (0, 2, 4 and 10 t ha^{-1}) at Matopos experimental site during 2006/07 growing season

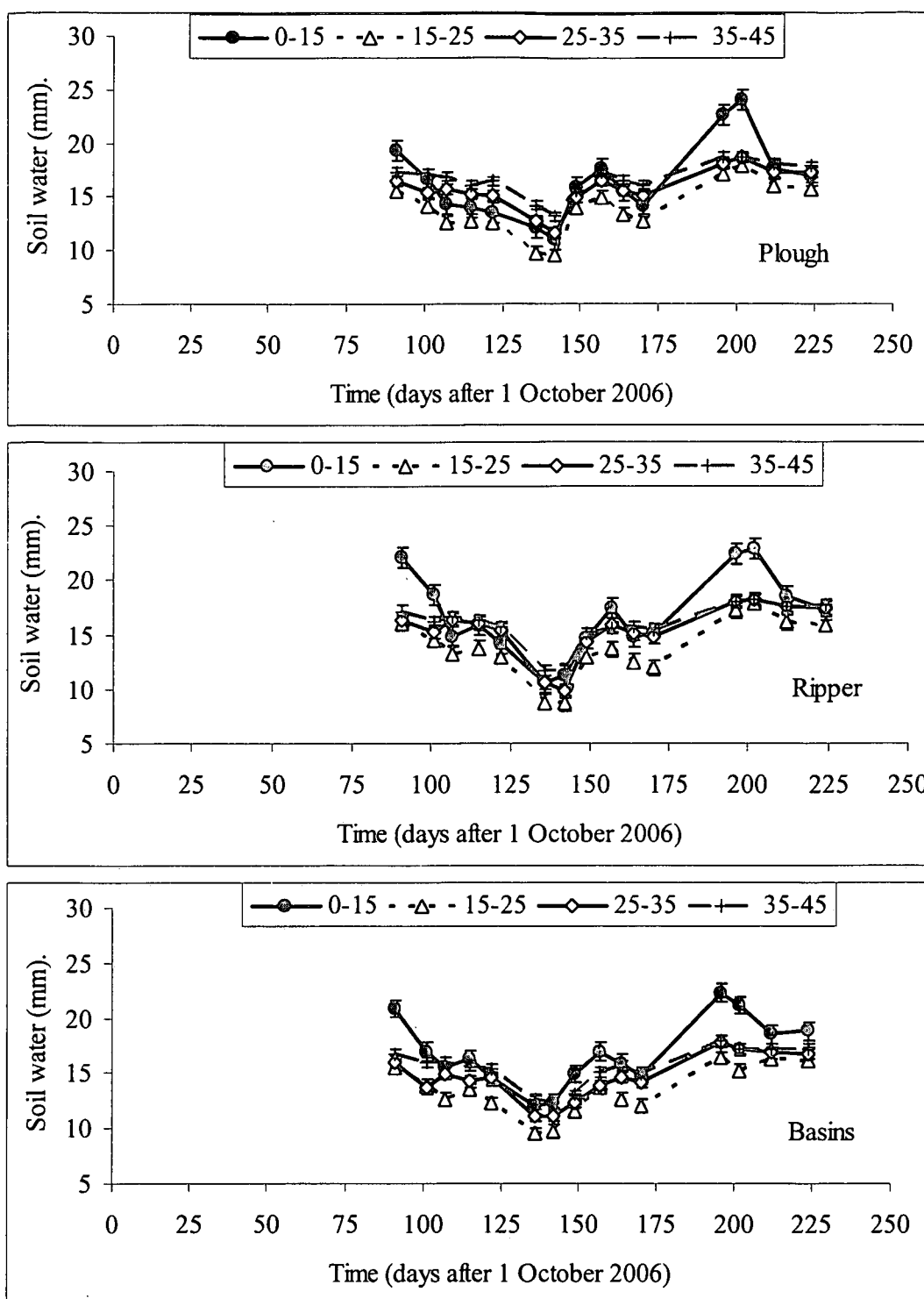


Figure 9a.8. Soil water changes in four different layers of the soil profile under the conventional ploughing, ripper and basin tillage systems during 2006/07 growing season at Matopos site

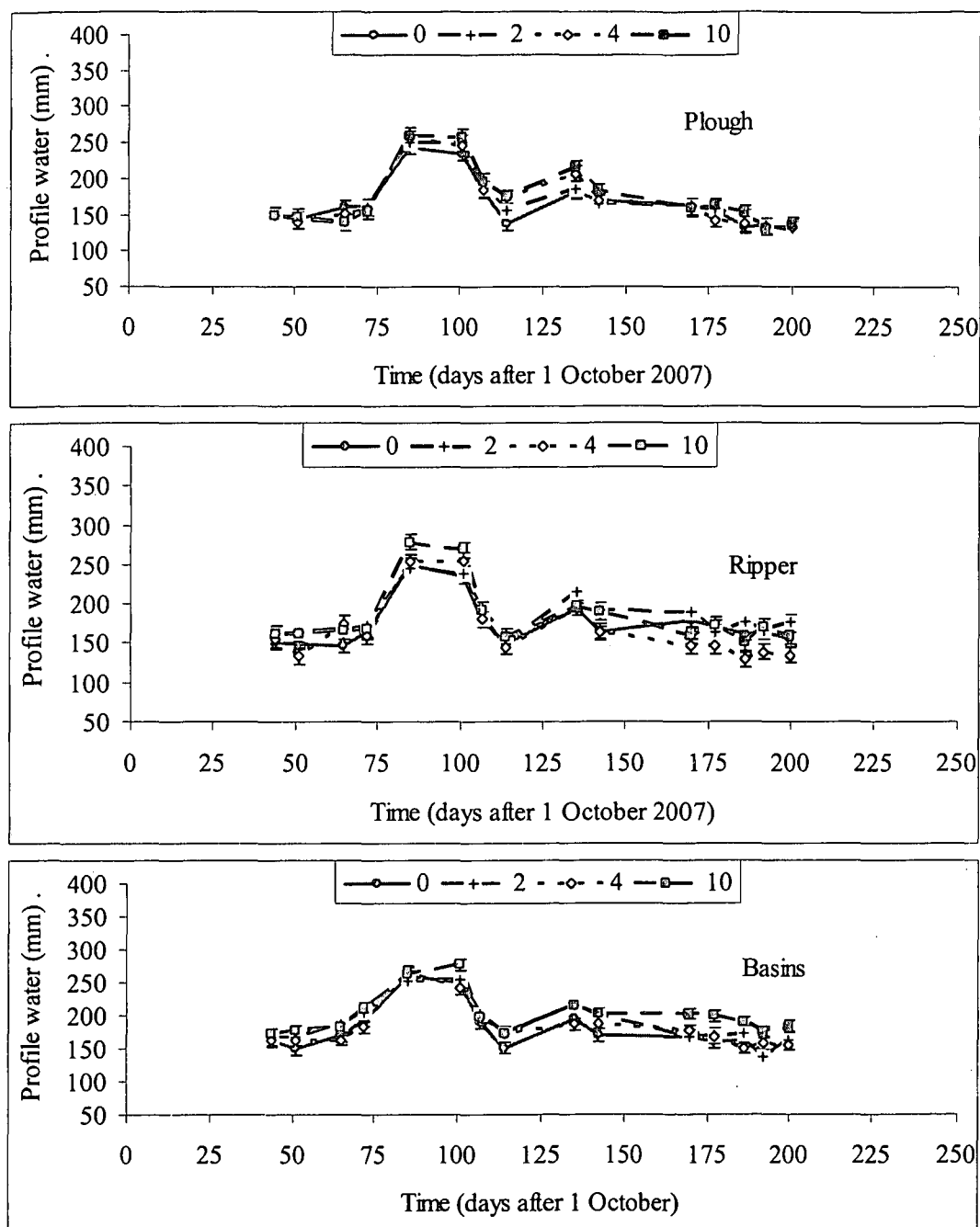


Figure 9a.9. Profile soil water changes in the conventional, ripper and basin tillage systems and four mulch treatments (0, 2, 4 and 10 t ha^{-1}) at Matopos experimental site during 2007/08 growing season

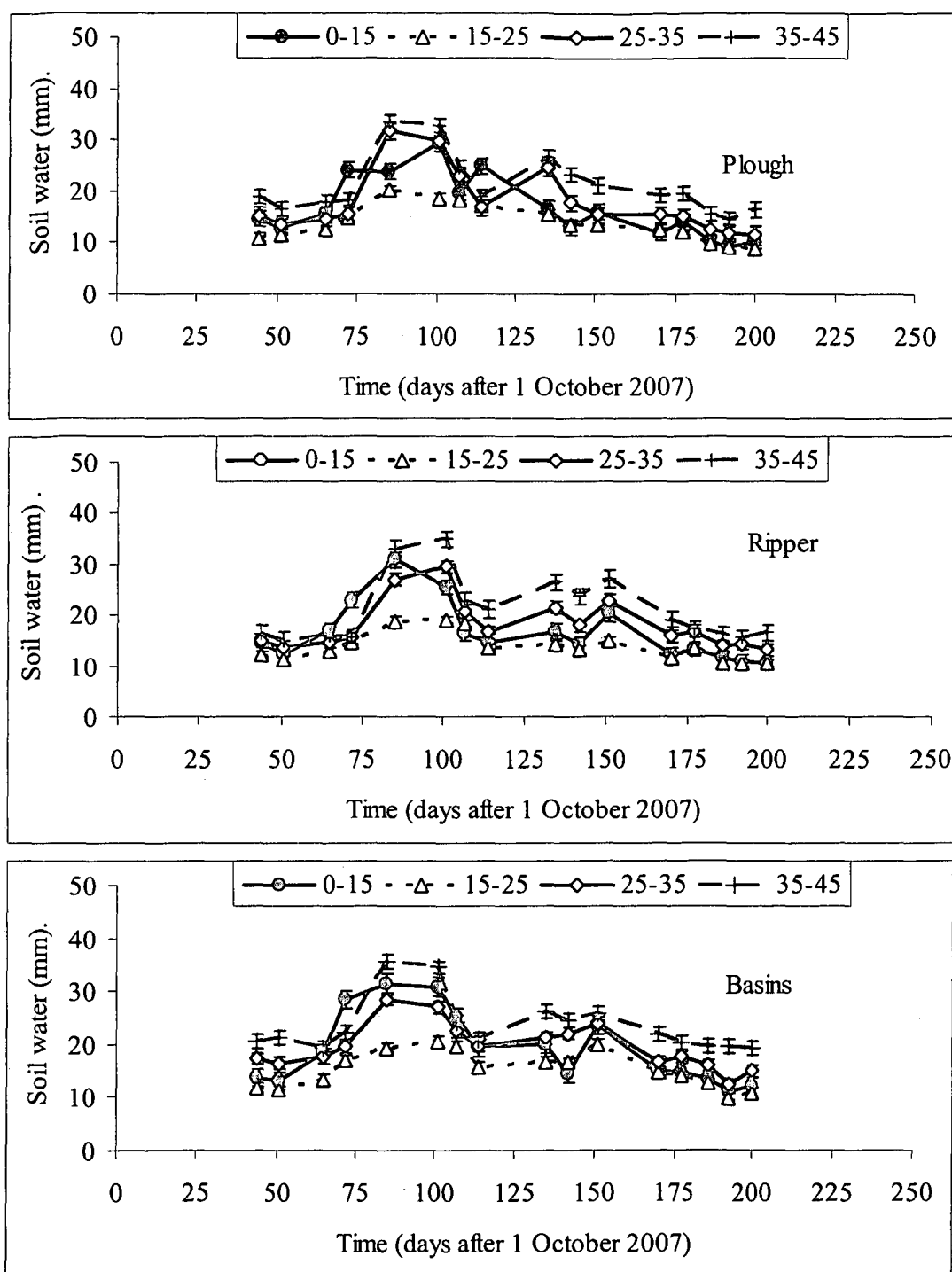


Figure 9a.10. Soil water changes in four different layers of the soil profile during 2007/08 growing season at Matopos experimental site

9a.4.3.3 Maize crop performance

The tillage system had no significant ($P > 0.05$) effect on maize grain production in the 2004/05 season. Tillage system and mulch rate interaction had no significant

influence on maize stover produced and harvest index. The two-way tillage and mulch interaction significantly ($P = 0.035$) influenced maize grain production at Matopos in 2004/05 growing season (Table 9a.7). The highest grain yield was recorded at 4 tha^{-1} mulch treatment in the conventional tillage system (Table 9a.7). The 1 tha^{-1} mulch treatment gave the highest yield in the ripper system while 10 tha^{-1} mulch cover out yielded the other mulch treatments under the basin system.

Table 9a.7. First year effects of tillage and mulch treatments on maize grain yield (kg ha^{-1}) at Matopos experimental site in 2004/05 growing season

Tillage	Mulch cover (tha^{-1})							Mean
	0	0.5	1	2	4	8	10	
Plough	2 106	2 269	2 527	2 429	3 243	2 547	2 514	2 519
Ripper	1 633	2 074	3 699	3 413	2 086	2 777	2 968	2 664
Basins	1 800	2 549	2 322	2 320	3 203	2 822	3 470	2 641
Mean	1 846	2 297	2 849	2 721	2 844	2 715	2 984	2 608

$\text{Lsd}_{0.05} = 1\,165 \text{ kg ha}^{-1}$, $\text{CV} = 26\%$

The two-way tillage x mulch interaction had a significant influence on maize crop establishment (Table 9a.8). At $4 - 10 \text{ tha}^{-1}$ mulch levels, the basin tillage system had a higher ($P < 0.05$) plant stand than the conventional and ripper systems. Under the 0 tha^{-1} mulch treatment, the conventional system had the lowest ($P < 0.05$) plant stand.

Table 9a.8. First year effects of tillage and mulch treatments on maize crop establishment (plants m^{-2}) at Matopos experimental site in 2004/05 growing season

Tillage	Mulch cover (tha^{-1})							Mean
	0	0.5	1	2	4	8	10	
Plough	1.7	3.0	3.3	3.0	2.0	2.0	2.3	2.5
Ripper	2.0	2.7	3.0	2.7	2.3	2.3	2.7	2.7
Basins	2.0	3.6	3.7	2.3	3.7	3.7	3.0	3.1
Mean	1.9	3.1	3.4	3.0	2.7	2.7	3.0	2.8

$\text{Lsd}_{0.05} = 0.92 \text{ plants per m}^2$, $\text{CV} = 21\%$

Contrary to our results presented previously from the Lucydale site in 2004/05 season (Table 9a.4), grain production was significantly ($P = 0.006$) influenced by mulch cover during 2004/05 season at Matopos. In all tillage systems grain yield recorded at 0 t ha^{-1} mulch treatment was lower than grain achieved at all other higher mulch cover. The clay soil at Matopos has a higher water holding capacity than the granitic sandy soil at Lucydale and the soil profile at Matopos was recharged by 128 mm of rain received in December and 119 mm recorded from 1 January to 25 January. There was more soil water held in the soil profile at Matopos than in the soil profile at Lucydale which the maize roots could access. Despite the 31 day dry spell recorded at the two sites the mulch cover could have conserved more soil water at Matopos than Lucydale, prolonging the period of soil water availability to the maize plants. Other researchers elsewhere have reported that mulching reduces soil evaporation thereby extending the period that soil water is available to crops (Zhai *et al.*, 1990; Sauer *et al.*, 1996; Erenstein, 2002).

At the end of a good rainfall 2005/06 season, neither tillage nor mulch treatments nor any combination of the two had a significant ($P > 0.05$) effect on all the maize production parameters measured at the Matopos site (Table 9a.9). Although there were no statistically significant effects of tillage on either stover or grain production, the basins out performed conventional ploughing at all except 2 and 10 t ha^{-1} mulch levels, and the ripper at mulch levels of 1 to 8 t ha^{-1} . The two-way tillage and mulch cover interaction did not have a significant influence on maize crop performance in a growing season with above average rainfall pattern. As observed at the Lucydale site soil water availability was not a constraint to maize crop growth during the 2005/06 growing season.

Table 9a.9. First year effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2005/06 growing season

Tillage	Mulch rate (tha ⁻¹)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index	Plant stand (m ⁻²)
Plough	0	3 795	6 124	0.35	2.8
	0.5	3 076	5 728	0.34	2.7
	1	4 388	5 765	0.40	2.6
	2	6 342	8 148	0.41	2.9
	4	5 108	7 161	0.39	2.7
	8	5 359	6 296	0.43	2.5
	10	4 947	6 543	0.42	2.7
	Mean	4 716	6 538	0.39	2.7
Ripper	0	4 947	5 642	0.43	2.8
	0.5	5 177	4 938	0.49	2.7
	1	5 536	6 333	0.43	2.7
	2	4 986	6 494	0.41	2.7
	4	4 950	5 580	0.44	3.0
	8	3 170	4 827	0.36	2.6
	10	5 369	6 124	0.44	2.7
	Mean	4 876	5 705	0.43	2.7
Basins	0	4 739	6 662	0.38	3.0
	0.5	4 975	6 617	0.40	3.2
	1	5 754	6 469	0.43	3.0
	2	5 687	7 408	0.41	3.2
	4	5 498	7 049	0.40	3.3
	8	5 379	7 284	0.39	2.9
	10	4 048	5 852	0.38	2.9
	Mean	5 154	6 763	0.40	3.1
Lsd _{0.05} (tillage)		2 382	3 332	0.049	0.95
Lsd _{0.05} (mulch)		1 212	1 071	0.047	0.24
Lsd _{0.05} (tillage x mulch interaction)		2 710	3 338	0.083	0.94
CV (%)		26	18	12	9.0

During the 2006/07 season, the tillage system had no significant ($P > 0.05$) influence on maize grain and stover production, and plant stand (Table 9a.10). However, in this season the basin system had significantly ($P = 0.011$) lower harvest index than conventional and ripper systems (Table 9a.10). The mean harvest indices observed were 0.36, 0.29 and 0.25 for conventional, ripper and basin systems. Mulching had a significant ($P < 0.001$) influence on maize grain production during 2006/07 growing season at Matopos. Maize grain production significantly increased with increase in

mulch cover particularly in the ripper and basin systems (Fig. 9a.13). The 2006/07 season received below average rainfall and there were dry spells lasting more than two weeks during January and February 2007. The increase in grain yields with increase in mulch cover (Table 9a.10) could be ascribed to the extension of the period when soil water was available to the maize crop under high mulch cover. Prolonging the period of soil water availability under high mulch treatments facilitated better grain filling as this is when dry spells occurred late in the season. Mulching had no significant influence on maize stover production and plant stand in the 2006/07 season.

In the 2007/08 growing season, tillage system and mulch treatment had no significant ($P > 0.05$) influence on maize grain and stover production, harvest index and plant stand (Table 9a.11). There were wide variations in plant stands across the treatments due to rodent damage particularly in the basins early in the season. Waterlogging in the ripper and basin plots during late December and January also resulted in the suppression of maize yields observed at the end of 2007/08 season. Lack of yield response to mulching is rather puzzling given the fact that the last rainfall event was recorded on 25 January 2008 but shows that the vegetative growth of the crop has a strong influence on the final crop yield. The maize crop endured more than two months without rain. The possible explanation is that the clay soil profile was saturated by the rains received in December 2007 and early January 2008, and there was enough soil water to take the maize crop to maturity regardless of the mulch cover.

Table 9a.10. First year effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2006/07 growing season

Tillage	Mulch rate (tha ⁻¹)	Grain yield (kgha ⁻¹)	Stover yield (kgha ⁻¹)	Harvest index	Plant stand (m ⁻²)
Plough	0	676	1 494	0.31	0.8
	0.5	1 045	1 543	0.38	1.1
	1	1 712	3 136	0.34	1.4
	2	1 536	2 420	0.36	1.4
	4	902	2 086	0.28	0.8
	8	2 018	2 025	0.46	1.1
	10	1 554	2 099	0.40	1.4
	Mean	1 349	2 115	0.36	1.1
Ripper	0	1 060	3 086	0.25	2.6
	0.5	1 148	1 679	0.38	1.4
	1	919	3 654	0.23	1.8
	2	1 456	3 790	0.26	1.3
	4	2 030	4 086	0.31	2.0
	8	1 857	3 444	0.34	1.5
	10	1 751	4 444	0.27	1.3
	Mean	1 460	3 455	0.29	1.7
Basins	0	735	4 111	0.14	2.5
	0.5	973	4 371	0.18	2.6
	1	1 210	3 876	0.24	1.9
	2	928	3 642	0.25	1.6
	4	1 570	3 000	0.33	1.5
	8	2 123	5 025	0.27	2.2
	10	2 129	3 852	0.33	1.9
	Mean	1 381	3 982	0.25	2.0
Lsd _{0.05} (tillage)		592	1 807	0.053	1.2
Lsd _{0.05} (mulch)		409	937	0.056	0.36
Lsd _{0.05} (tillage x mulch interaction)		794	2 074	0.098	1.2
CV (%)		31	31	20	23

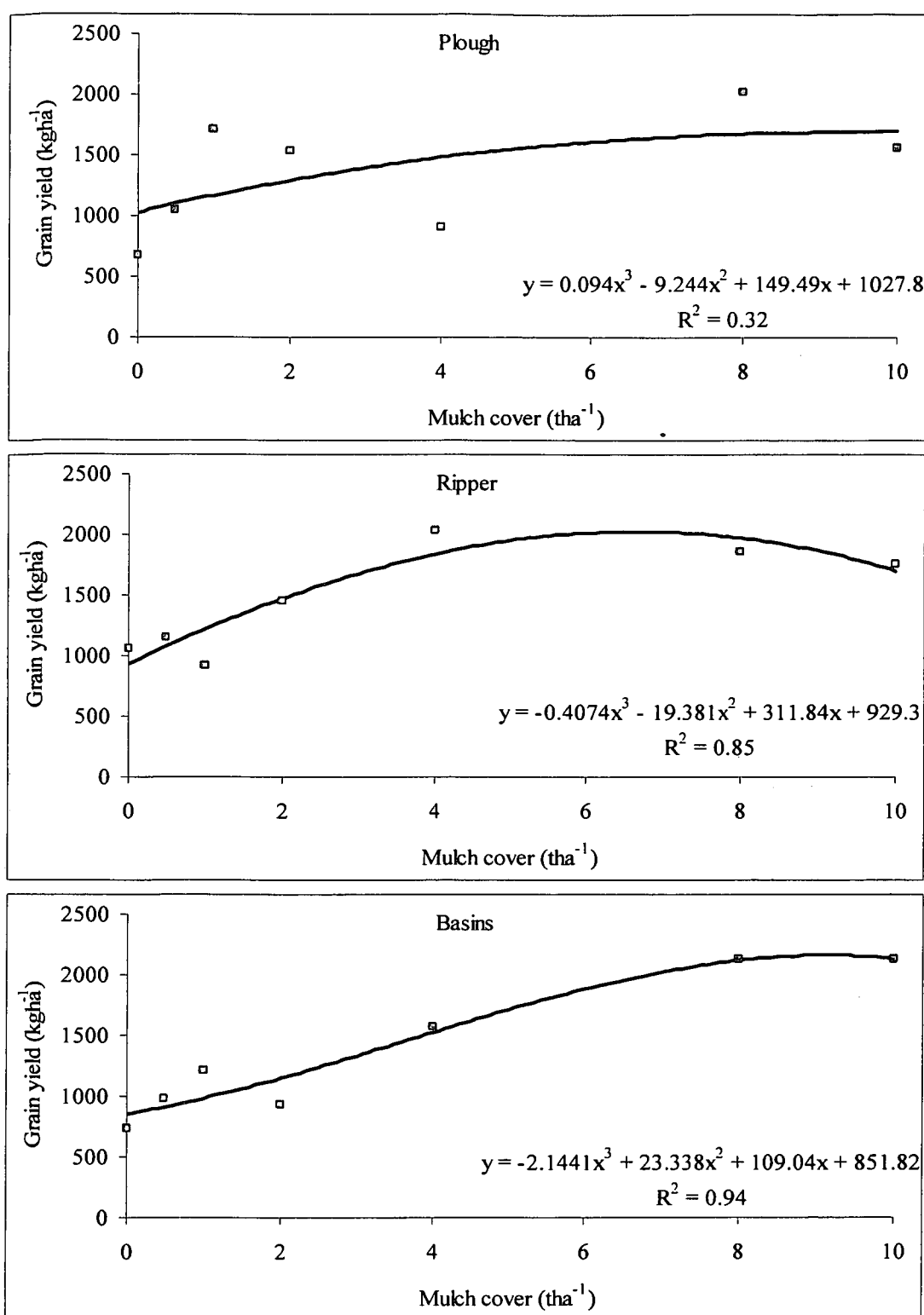


Figure 9a.11. Maize grain yield responses to mulching on a red clay soil under conventional, ripper and basin tillage system during the 2006/07 growing season

Table 9a.11. First year effects of tillage and mulch treatments on maize crop performance at Matopos experimental site in 2007/08 growing season

Tillage	Mulch rate (tha ⁻¹)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index	Plant stand (m ⁻²)
CP	0	1 504	1 741	0.39	1.9
	0.5	1 507	1 321	0.46	1.7
	1	1 129	1 210	0.40	1.6
	2	664	815	0.40	1.5
	4	1 218	1 272	0.41	1.5
	8	1 163	1 284	0.42	1.4
	10	1 878	1 543	0.47	1.9
	Mean	1 295	1 312	0.42	1.6
Ripper	0	1 257	1 296	0.42	1.8
	0.5	2 211	1 790	0.48	2.2
	1	1 194	1 210	0.43	1.8
	2	1 202	1 198	0.42	1.8
	4	1 162	1 333	0.41	1.8
	8	1 686	1 679	0.44	2.0
	10	1 100	1 210	0.43	1.8
	Mean	1 402	1 388	0.43	1.9
Basins	0	1 123	1 296	0.40	1.6
	0.5	964	1 173	0.41	1.5
	1	971	1 185	0.41	1.8
	2	1 009	1 136	0.41	2.2
	4	1 076	1 271	0.40	1.7
	8	781	1 037	0.39	1.3
	10	519	704	0.30	1.1
	Mean	920	1 115	0.39	1.6
Lsd _{0.05} (tillage)		613	738	0.060	1.45
Lsd _{0.05} (mulch)		428	419	0.066	0.32
Lsd _{0.05} (tillage x mulch interaction)		828	883	0.114	1.42
CV (%)		37	34	17	13

9a.4.3.4 Maize crop performance across four growing seasons

The maize crop performance differed significantly ($P < 0.001$) across the four seasons of experimentation. All measured production parameters were significantly ($P < 0.001$) influenced by season with 2005/06 having the highest grain and stover yields, and plant stand (Table 9a.12). Measured mean grain yield was 2 656, 4 937, 1 397 and 1 206 kg ha⁻¹ for 2004/05, 2005/06, 2006/07 and 2007/08 seasons. Mean stover yields were 2 948, 6 376, 3 136 and 1 272 kg ha⁻¹ for 2004/05, 2005/06, 2006/07 and 2007/08

seasons. Maize harvest indices ranged from 0.30 to 0.43 while the highest plant stand recorded across the four seasons was 3.7 plants m⁻².

Table 9a.12. Effect of the growing season on maize crop performance at Matopos experimental site

Season	Grain (kg ha ⁻¹)	Stover (kg ha ⁻¹)	Harvest index	Plant stand (plants m ⁻²)
2004/05	2 656	2 948	0.43	2.7
2005/06	4 937	6 376	0.41	3.7
2006/07	1 397	3 136	0.30	1.8
2007/08	1 206	1 272	0.40	1.7
Lsd _{0.05}	390	438	0.023	0.20
CV (%)	43	36	17	23

The two seasons at Lucydale and four seasons at Matopos were characterised by different rainfall distributions (Figs. 9a.1 and 9a.4). The relatively wet 2005/06 season had the highest yields on both soil types regardless of the tillage system used. Studies conducted in northern Zimbabwe by Smith (1988) over a 10 year period indicated that rainfall characteristics during the season has more influence on maize crop performance than tillage systems such as conventional ploughing, ripping and zero tillage. The dry spells observed in the 2004/05, 2006/07 and 2007/08 seasons substantially reduced maize yields. The dry spells experienced during this project all coincided with flowering and grain filling stages of the maize crop during the second half of the season. In West Africa Rockström and de Rouw (1997) observed significant pearl millet yield reduction when dry spells occurred during the flowering stage of the cereal crop.

The tillage system had no significant ($P > 0.05$) influence on any of the measured parameters across the four seasons. Generally maize grain production increased ($P = 0.010$) with increase in mulch application rate up to 8 t ha⁻¹ (Table 9a.13). The lowest

($P = 0.045$) harvest index was recorded at 0 t ha^{-1} mulch treatment while the least ($P = 0.005$) plant stand was observed at 0 and 8 t ha^{-1} mulch treatments. The two-way tillage system and mulch treatment interaction had no significant ($P = 0.325$) influence on maize crop performance. The three-way tillage, mulch and season interaction also failed ($P = 0.580$) to influence any of the measured parameters of the maize crop.

Table 9a.13. Effects of tillage and mulching on maize performance averaged across four growing seasons at Matopos experimental site

Treatment		Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index	Plant stand (plants m^{-2})
<i>Tillage</i>	CP	2 470	3 251	0.40	2.6
	Ripper	2 602	3 386	0.39	2.3
	Basins	2 575	3 661	0.38	2.5
	Mean	2 549	3 433	0.39	2.5
	Lsd _{0.05}	818	1 107	0.022	0.52
<i>Mulch</i>	0	2 153	3 237	0.36	2.3
	0.5	2 331	3 093	0.40	2.6
	1	2 613	3 602	0.38	2.6
	2	2 664	3 654	0.38	2.5
	4	2 670	3 466	0.39	2.4
	8	2 723	3 540	0.40	2.3
	10	2 687	3 439	0.40	2.4
	Mean	2 549	3 433	0.39	2.4
Lsd _{0.05}		344	460	0.029	0.18
CV (%)		43	36	17	23

9a.5 Conclusion

The four seasons of experimentation demonstrated that rainfall distribution during the growing period is the key to successful cropping in semi-arid southern Zimbabwe. Rainfall in two of the four seasons of experimentation started well in November but that early start was not a guarantee for good distribution during the growing season. Mid-season dry spells and abrupt cessation of rains occurred in seasons with below average rainfall pattern and that had a negative impact on maize yields even on well managed on-station experiments. This means that the level of farmer management and

care of the crop should be increased because any mishap at the beginning of the season can be carried with the crop through to the yield.

Soil water dynamics were quite similar under the conventional ploughing, ripper and basin tillage systems and mulch cover treatments even in seasons with below average rainfall. This implies that there are equal chances of having reduced crop yields or total crop failure if a smallholder farmer in southern Zimbabwe is using single conventional ploughing, ripper or basin tillage systems combined with mulch cover in the event of a drought or prolonged dry spell. Researchers have a task of modifying the CA systems so that they can deal with the variable rainfall pattern of semi-arid areas such as southern Zimbabwe. The 10 t ha⁻¹ mulch treatment had more soil water in the profile than the lower mulch treatments in basin and ripper systems but this soil water advantage was not translated into maize yield. This study revealed that crop stands and ultimately yields in the basin system can be reduced by rodents in some drought years and by waterlogging in wet seasons. Smallholder farmers using the basin system can therefore fail to benefit from the seasons with good rainfall distribution if crop stand is poor.

The conventional, ripper and basin systems gave similar maize yields regardless of the rainfall pattern during the growing season. Although the tillage system had no significant influence on maize yields in seasons of varying rainfall patterns, the use of ripper and planting basin tillage systems offers smallholder farmers an opportunity to plant with the first effective rains. Therefore smallholder farmers in semi-arid southern Zimbabwe have a range of tillage options to choose from depending on their resource status. As demonstrated in 2004/05 and 2006/07 seasons mulching improves

maize yields in drought years. Although the highest maize yields were achieved at 8 tha^{-1} mulch rate, there were no significant yield benefits derived from increasing mulching rate from 1 to 10 tha^{-1} . Given the low cereal and legume biomass production of the semi-arid smallholder systems and crop-livestock competition for crop residues, mulch levels of 4 – 10 tha^{-1} might be impossible despite the little soil water and crop yield benefits observed in this study. Smallholder farmers can therefore target using 2 tha^{-1} mulch cover when embarking on conservation farming practices.

CHAPTER 9b

Minimum Tillage and Mulching Effects on Soil Water Regimes, and Cowpea and Sorghum Yields on a Red Clay Soil in Semi-Arid Southern Zimbabwe

9b.1 Introduction

Cowpea (*Vigna unguiculata* (L.) Walp) and sorghum (*Sorghum bicolor* (L.) Moench) are traditionally grown as subsistence crops in the smallholder sector of sub-Saharan Africa. Both crops are considered to be drought tolerant and commonly grown as sole or intercrops in the smallholder farming systems of Zimbabwe (Nhamo *et al.*, 2003), but rarely in a planned rotation (Ncube *et al.*, 2007). However, where rotation of cowpea with cereals such as sorghum do occur, utilization of soil water and nutrients from different soil depths may be promoted both within and between seasons (Moroke *et al.*, 2005; Ncube *et al.*, 2007). For example, some improved cowpea varieties mature early, and have the potential to allow some carryover of stored soil water from one season to the next, for the following cereal crop.

Agricultural land management practices such as mulching and minimum tillage can improve soil water supply to crops through reduced runoff and soil evaporation, increased infiltration and water storage (Zaongo *et al.*, 1997; Hatfield *et al.*, 2001; Erenstein, 2002; Lipic *et al.*, 2005). Studies conducted in the higher potential areas of Zimbabwe between 1988 and 1995 indicated that mulching significantly reduced surface runoff and hence soil loss (Erenstein, 2002). The mulching material at the soil-atmosphere interface holds rainwater at the soil surface thereby giving it more time

to infiltrate into the soil. Mulch cover also shields the soil from solar radiation thereby reducing the energy available for evaporation from the soil.

Conservation agriculture is a system that encourages minimum soil disturbance and the use of crop residue as mulch cover for improved soil water and weed management among other benefits. It emphasizes rotation of cereals and legumes in a permanent grid of planting positions. A fixed grid of planting positions is established during the dry season and nutrients are applied to those fixed planting stations (Twomlow *et al.*, 2008a). However, the challenge lies in accommodating legumes and cereals in similar planting positions each growing season without compromising on the principle of minimum soil disturbance or yield of either the cereal or legume crop. Basically does a permanent planting grid designed for cereals compromise yields for legume crops? This chapter focuses on the cowpea and sorghum yield responses in consecutive seasons following the planting of an initial maize crop.

9b.2 Objectives

This on-station experiment was designed to determine

- (1) effect of planting basin, ripper and conventional tillage systems and mulching on soil water regimes under cowpea and sorghum crops;
- (2) effect of planting basin, ripper and conventional tillage systems and mulching on cowpea and sorghum yields; and
- (3) optimum mulching rate for semi-arid Zimbabwe.

9b.3 Materials and Methods

9b.3.1 Experimental set up

The experiment was established at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Matopos Research Station, for two growing seasons on a clay loam soil. In 2004/2005 season the maize phase 1 was established and planted to a sole maize crop (see Table 9a.1 in Chapter 9a). In 2005-2006, as part of planned rotation for the experiment, a cowpea crop (cowpea phase 1) was planted in the field that was previously under maize phase 1. In the same 2005/06 season, maize phase 2 was established on an adjacent plot of land and planted to a sole maize crop. As part of the planned rotation a cowpea crop (cowpea phase 2) was planted in the 2006/2007 season on the field which was previously under maize phase 2. In 2006/07 season a sorghum phase was established in the field that was previously under cowpea phase 1. Maize phase 3 was established on a new field that was adjacent to maize phase 1 and planted to a sole maize crop. In the 2007/08 season maize phase 4 was established on a new field and also on the three fields that were previously under maize phase 3, cowpea phase 2 and sorghum phase the previous year. The experiment was set up using a split plot design with three replications. The main plot factor was tillage method (planting basins, ripper and conventional plough) with mulch cover (0, 0.5, 1, 2, 4, 8 and 10 tha^{-1}) as a subplot factor. Plots were pegged out in October of each maize phase, and then maintained in subsequent seasons.

Tillage was established on 63 m $\times$ 6 m strips and seven mulch levels were randomly allocated to sub-plots measuring 8 m $\times$ 6 m on each tillage treatment. Each plot was

separated by a 1 m pathway to avoid movement of residue from one plot to the next when tillage was undertaken. All tillage operations were carried out after applying mulching material to each sub-plot. Planting basins were dug at 0.6 m × 0.9 m spacing using a hand hoe and each basin measured 0.15 m (length) × 0.15 m (width) × 0.15 m (depth), disturbing less than the equivalent of 1000 m² ha⁻¹. Rip lines were opened at 0.9 m inter-row spacing using a ripper tine attached to the beam of a donkey-drawn mouldboard plough. The ripping depth achieved varied between 0.15 and 0.18 m, with a surface width disturbance of 0.12 m, disturbing less than the equivalent of 1 440 m² ha⁻¹. Conventional ploughing was done soon after the first effective rain in December each year using a donkey-drawn VS 100 mouldboard plough. Planting furrows were then opened at the appropriate inter-row spacing for the crop of 0.6 m. An in-row spacing of 0.2 m between seeds was used in conventional and ripper systems.

The cowpea variety used was a semi-determinate 86D 719 which matures in 120 days (Ncube, 2007). The sorghum Macia variety was used as it is recommended for the semi-arid environments of southern Zimbabwe. In 2005/06 the cowpea phase 1 of the rotation was planted on 16 December 2005. In 2006/07 season, planting in the basin and ripper systems was done on 22 November 2006 for, the cowpea phase 2. Planting of cowpea in the conventional system was done on 8 December 2006 because the soil was too wet to plough. Planting in the sorghum phase, was done on 14 December 2006. In the cowpea and sorghum phases, five seeds were planted per basin while two seeds were planted per station in the conventional and ripper systems. For the cowpea phase of the rotation, plants were thinned to four per basin in planting basin and one plant per station in the

ripping and conventional tillage treatments two weeks after emergence. For the sorghum phase of the rotation, plants were thinned to two per basin in the planting basin system and one per station in the ripper and conventional tillage treatments two weeks after emergence. Weeds were controlled by hand hoe as required in all seasons.

In the 2005/06 season gravimetric soil water was determined by collecting soil samples fortnightly between planting basins, along riplines and in rows for conventional tillage treatments. Soil samples were collected at 0.15 m depth interval up to a maximum depth of 0.60 m. The soils were weighed before oven drying them at 105°C for 48 hours for determining gravimetric water content. Gravimetric water content for each soil layer was calculated using the procedure outlined by Anderson and Ingram (1993). Gravimetric water content was converted to volumetric water content for each respective depth using the measured bulk density for each soil layer. Soil water content in millimetres was determined by multiplying volumetric water content by thickness of each layer from which soil water was measured. In the 2006/07 growing season soil water was measured weekly at 0.1 m depth interval using a capacitance probe (microgopher type).

9b.3.2 Data collection and analysis

Daily rainfall was measured by a standard raingauge throughout each season. At harvest grain yield was estimated from a net plot consisting of the five middle rows of 6 m length. Grain samples were dried at 60 °C for 48 hours for moisture adjustment. Grain weight was converted to a per hectare basis at 12.5% moisture content. All data were analyzed by ANOVA using Genstat Discovery Edition 3 (www.vsnl.co.uk) with split plot

design for cowpea and sorghum yield data, and unbalanced design for soil water data. Then the least significant difference (Lsd) at 5 % significance level was used to compare tillage treatment means.

9b.4 Results and Discussion

9b.4.1 2005/06 season

9b.4.1.1 Seasonal rainfall and soil water changes

The total seasonal rainfall for 2005/06 growing season was 832 mm, with 298 mm of this having fallen before the cowpea phase 1 was planted on 16 December 2005 (day 77). The 2005/06 season's rainfall was 45 % more than the 69 year average rainfall for Matopos (Chapter 4). Rainfall events, totalling 294 mm observed between 1 December (day 62) and 12 December (day 73) filled up the 0 – 0.30 m soil profile of all tillage systems (Fig. 9b.1).

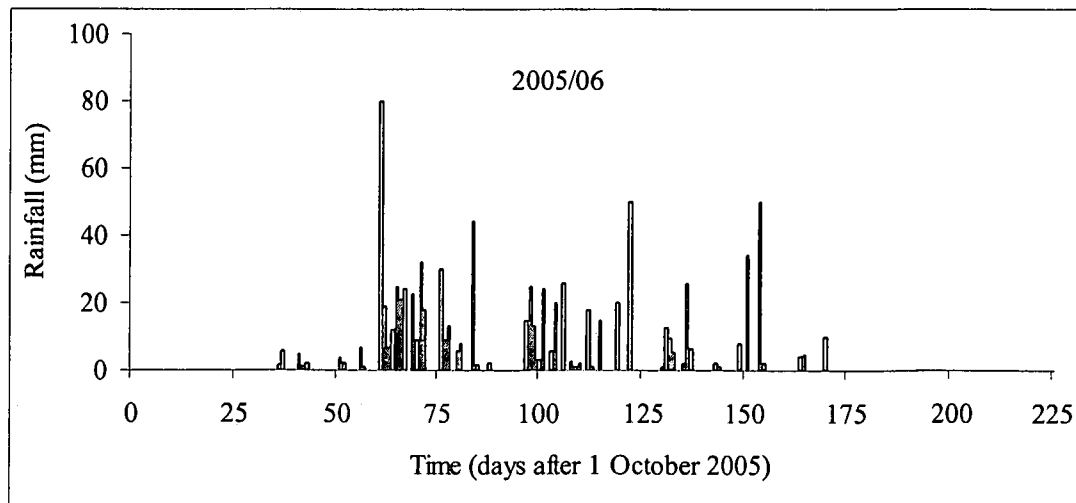


Figure 9b.1. Daily rainfall distribution at Matopos site during the 2005/06 growing season

Drying of the 0 – 0.30 m soil profile started after 28 December 2005 (day 89) until 8 February 2006 (day 131) despite a further 256 mm of rainfall falling during this period. Soil water was being extracted by cowpea roots as the crop was in its vegetative and flowering stages between these dates. Soil water contents increased steadily in response to rainfall received between 8 February (day 131) and 6 March (day 157). On 6 March 2006, the 4 t ha⁻¹ mulch treatment had on average 17, 28, and 30 mm more soil water than 10, 2 and 0 t ha⁻¹ mulch treatments under the conventional ploughing tillage system (Fig. 9b.2) following a 50 mm rainfall event recorded on 3 March (day 154). On the same day the ripper system had 16, 24 and 16 mm more soil water in the 4 t ha⁻¹ mulch treatment than 0, 2 and 10 t ha⁻¹ treatments respectively. Under the planting basin system the 0, 2 and 4 t ha⁻¹ mulch treatments had similar soil water content but the 10 t ha⁻¹ mulch treatment had 22 % less water than the other three mulch treatments on 6 March 2006 (day 151) (Fig. 9b.2).

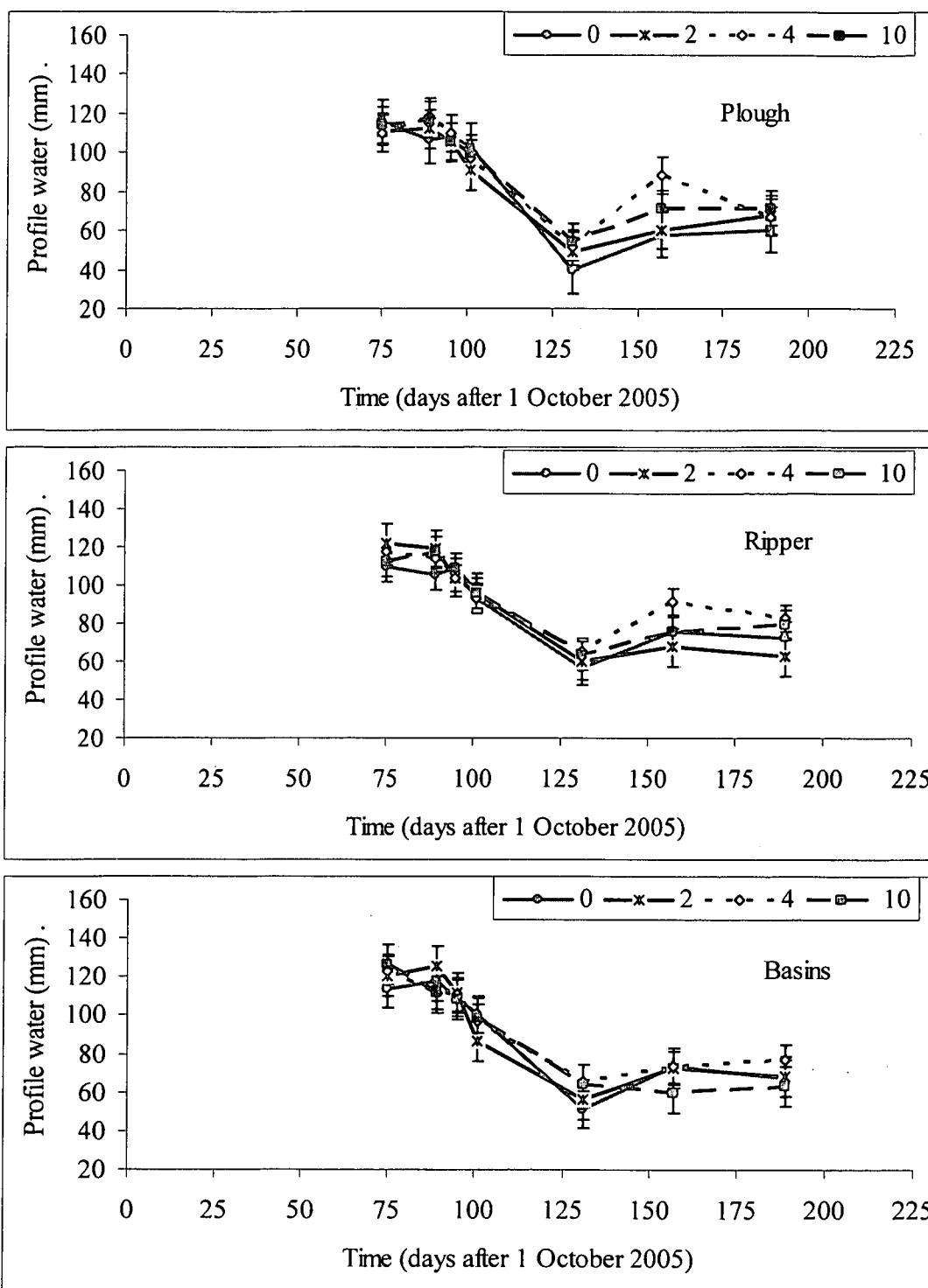


Figure 9b.2. Soil water changes in 0 – 0.30 m profile in the cowpea field under conventional ploughing tillage system and four mulch treatments (0, 2, 4 and 10 t ha⁻¹) on a clay soil during 2005/06 growing season. Error bars represent standard error of means

9b.4.2 2006/07 season

9b.4.2.1 Seasonal rainfall and soil water regimes

The total seasonal rainfall for 2006/07 growing season was 465 mm of which 104 mm was accumulated between 13 November (day 44) and 22 November (day 53) (Fig. 9b.3). The 2006/07 total season's rainfall was 23 % less than the 69 year average rainfall for Matopos (Chapter 4). The month of January 2007 received very low rainfall of only 12 mm recorded on 17 January (day 110). February and March 2007 received 80 and 77 mm of rain with the 2006/07 season ending on 4 April 2007 (see Table 9a.6 in Chapter 9a). The cowpea crop experienced soil water stress during the 14-16 day dry spells experienced in January 2007 (Fig. 9b.3) and went on to give similar yields to those observed by Ncube *et al.* (2007) in 2004/05 season on a sandy soil. This can be attributed to the ability of cowpea to extract soil water from soils with low water content. Cowpea has a uniform rooting system that increases its surface area and enables the plant to extract soil water from a microscale even in drying soils (Hall, 2004).

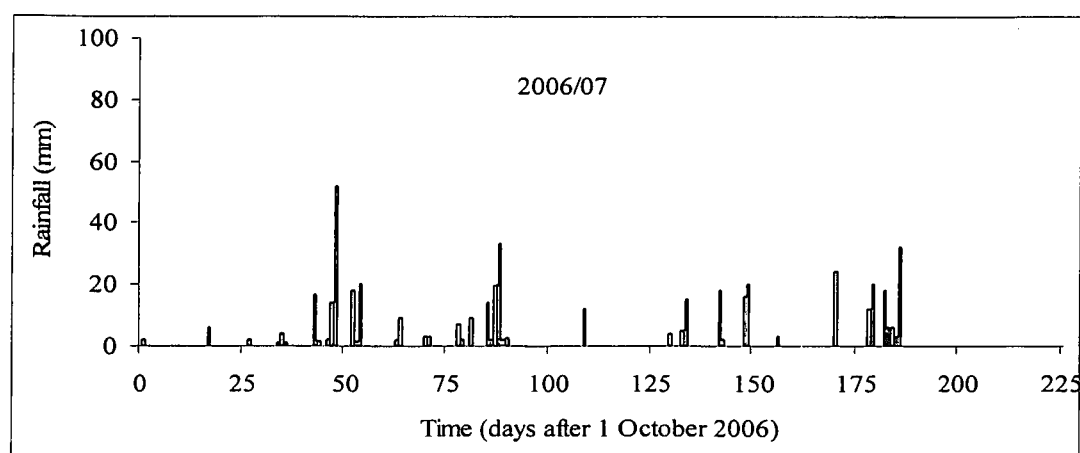


Figure 9b.3. Daily rainfall distribution at Matopos site during the 2006/07 growing season

Profile soil water content to a depth of 0.55 m responded to rainfall events (Fig. 9b.4) and the pattern of soil water changes was quite similar in the three tillage systems and four mulch treatments. On 15 November (day 46) profile water content was higher ($P < 0.001$) under 10 t ha^{-1} mulch treatment than 0, 2 and 4 t ha^{-1} in the conventional tillage system (Fig. 9b.4). The 10 t ha^{-1} mulch cover probably captured more rainwater from the 18 mm rainfall event observed on 13 November 2006 (day 44). A total of 50.5 mm rainfall was received between 15 November (day 46) and 8 December (day 69). Profile soil water measured on 8 December 2006 showed that under the conventional tillage system there was an average of 105 mm of water under the 0 t ha^{-1} mulch treatment, 90 mm under the 2 t ha^{-1} , 127 mm under the 4 t ha^{-1} and 116 mm under the 10 t ha^{-1} . In the basin system, profile water content on 8 December was 149, 169, 185 and 153 mm under 0, 2, 4 and 10 t ha^{-1} mulch treatments which are all much higher than the conventional plough. The ripper system had similar profile water content under 0, 2, 4 and 10 t ha^{-1} mulch treatments on 8 December 2006. Profile water content recorded on 12 February 2007 (day 134) showed that under the conventional system there was 44 mm at 0 t ha^{-1} mulch cover, 36 mm at 2 t ha^{-1} , 48 mm at 4 t ha^{-1} and 51 mm being recorded at 10 t ha^{-1} . In the ripper tillage system profile water content on 12 February was 46, 49, 52 and 52 mm under 0, 2, 4 and 10 t ha^{-1} mulch treatments which were marginally higher than the conventional system. Profile water content under the planting basin system was 44 mm at 0 t ha^{-1} mulch cover, 46 mm at 2 t ha^{-1} , 54 mm at 4 t ha^{-1} and 56 mm at 10 t ha^{-1} mulch treatments.

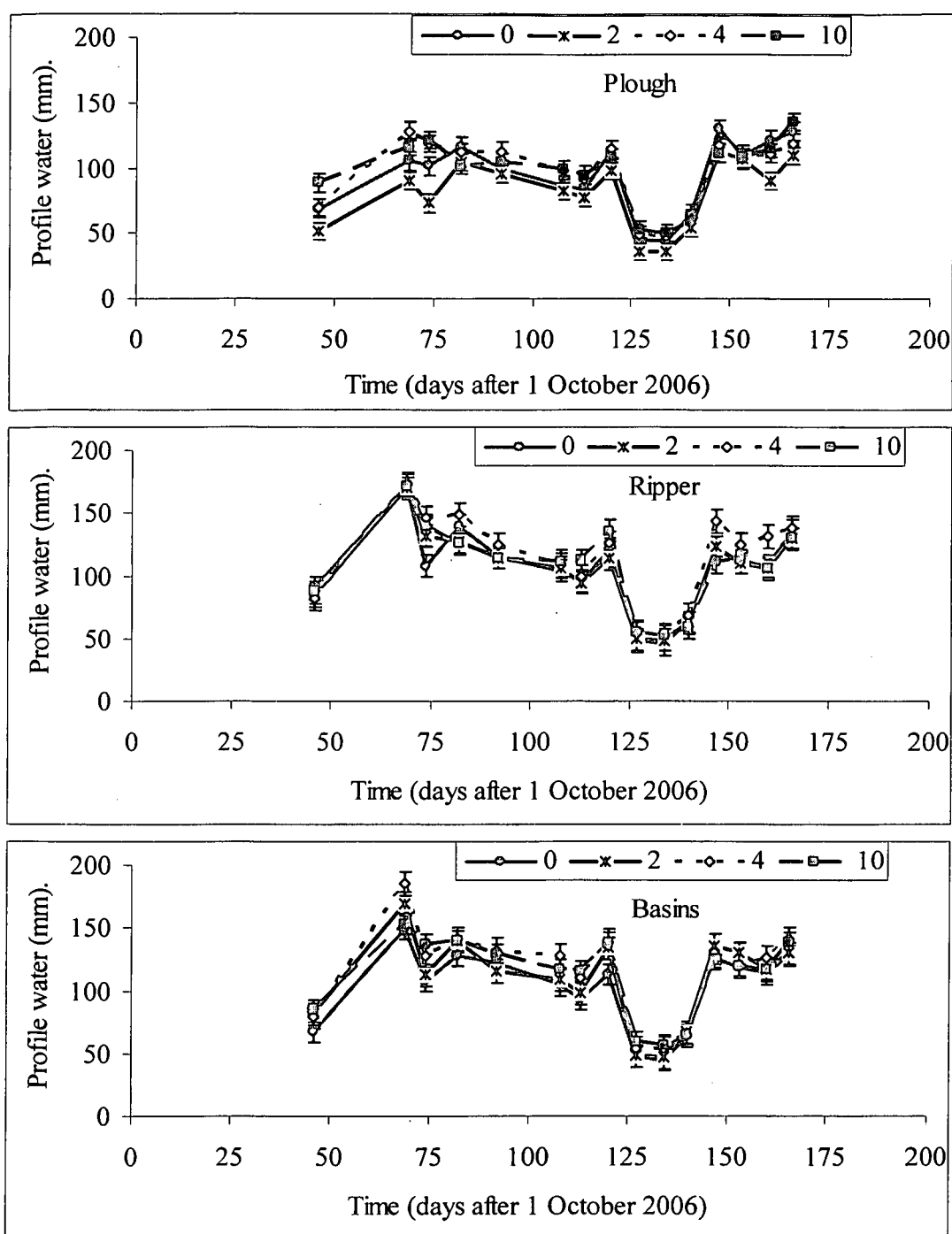


Figure 9b.4. Profile soil water changes in 0 – 0.55 m profile in the cowpea field under conventional, ripper and basin tillage systems and four mulch treatments (0, 2, 4 and 10 t ha⁻¹) on a clay soil during 2006/07 growing season. Error bars represent standard error of means

9b.4.2.2 Water changes in different soil layers under three tillage systems (cowpea field)

Soil water content in the different layers varied significantly ($P < 0.001$) especially between November 2006 and February 2007 (Figs. 9b.5 and 9b.6). In each tillage system, the top layer (0-0.15 m) responded to rainfall events more strongly than deeper layers as expected. The top layer also lost soil water faster by soil surface evaporation during drying cycles. The 0.15-0.25 m layer was the driest throughout the season indicating that there was good cowpea root distribution within this layer to extract the water. Most cowpea roots are reportedly concentrated in the top 0.5 m soil layer and root density decreases progressively with soil depth (Zaongo *et al.*, 1997; Moroke *et al.*, 2005). Soil water could be saved in the top soil layers for the cowpea crop by applying surface mulch cover.

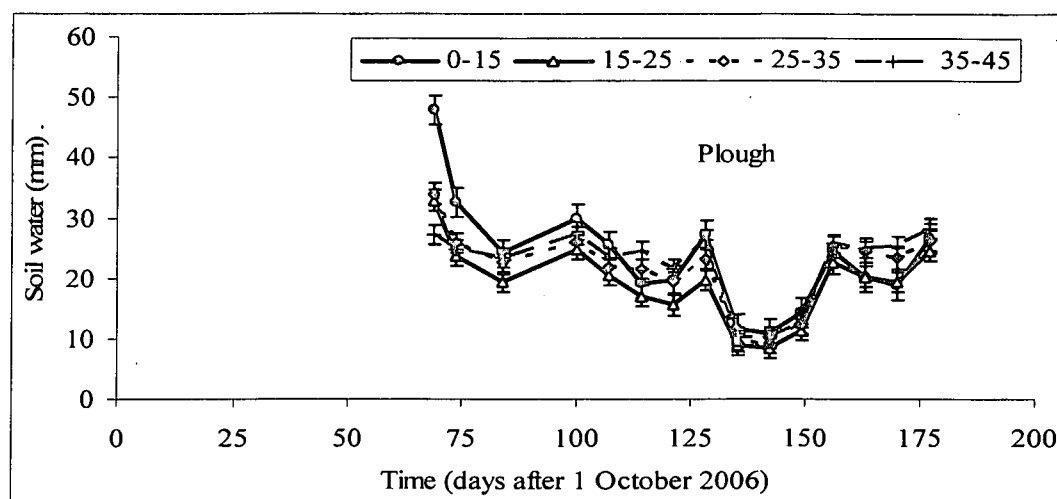


Figure 9b.5. Average changes in equivalent soil water depth in different layers of a clay soil under conventional ploughing tillage system in the cowpea field at Matopos Research Station during 2006/07 growing season. Error bars indicate standard error of the means

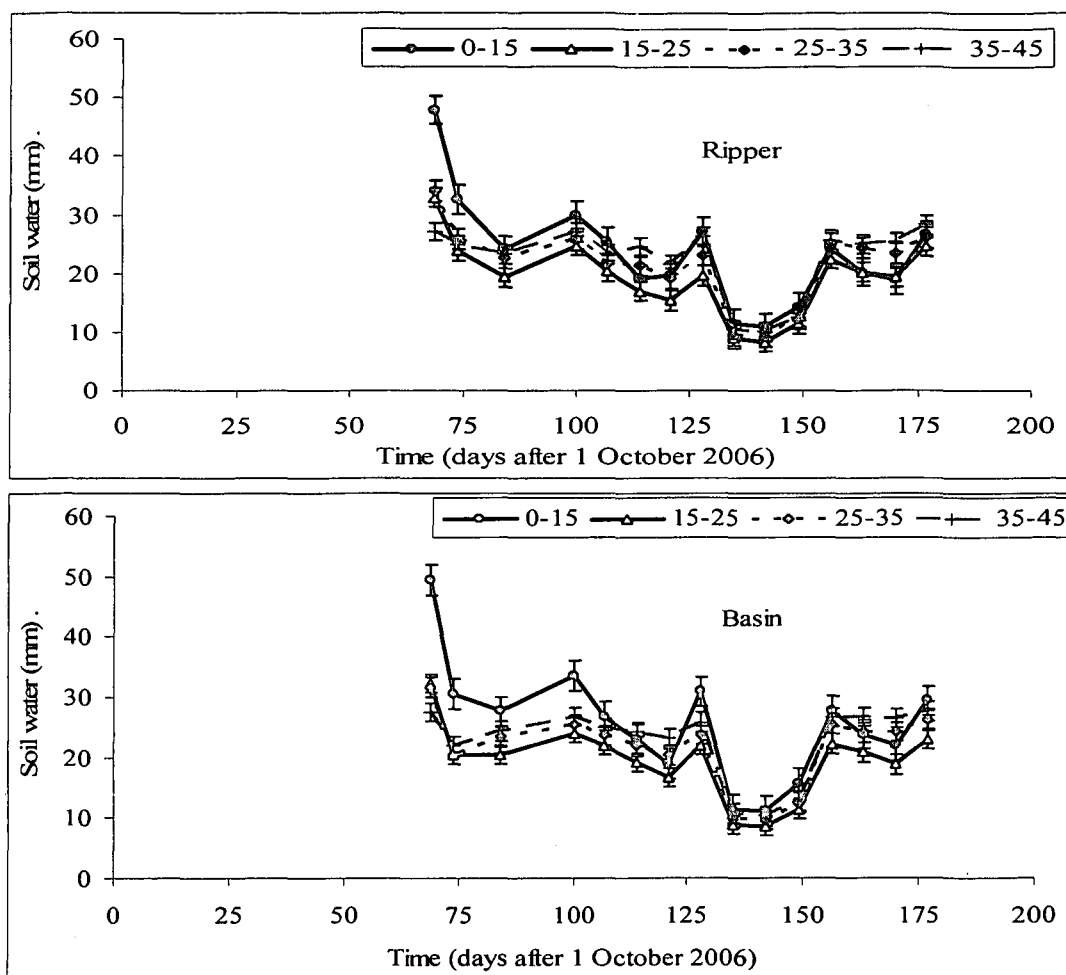


Figure 9b.6. Average changes in equivalent soil water depth in different layers of a clay soil under ripper and basin tillage systems in the cowpea field at Matopos Research Station during 2006/07 growing season. Error bars indicate standard error of the means

9b.4.2.3 Soil water regimes in the sorghum field (sorghum phase)

The soil water measurements in the sorghum field on 15 November 2006 were the highest throughout the growing season across all treatments which is a month before planting (Figs. 9b.7). There were little differences in the total profile water content between mulch treatments under the same tillage system and across tillage systems throughout the whole season, with values remaining around 100 mm. The soil water

patterns in a clay soil under cowpea and sorghum crops were quite similar in a season with below average rainfall. This is consistent with results from Ncube *et al.* (2007) who observed similar soil water dynamics (0 – 0.25 m soil layer) in sorghum and grain legume fields on a sandy soil. On 15 November (day 45) ripper and basin tillage systems had a greater ($P < 0.001$) depth of equivalent soil water in the 0 – 0.65 m profile than conventional tillage system. Conventional ploughing had not yet been done by 15 November 2006 while ripped furrows and planting basins had been prepared by 15 October 2006. The basin and ripper tillage systems collected rainwater from the rainfall events recorded between 1 October and 14 November 2006 amounting to 34 mm. The 10 t ha^{-1} mulch treatment had 39, 40 and 38 mm of soil water more than 0, 2 and 4 t ha^{-1} treatments in the conventional system. On the same day in the ripper system, the 10 t ha^{-1} mulch treatment had 23, 30 and 25 mm more soil water than 0, 2 and 4 t ha^{-1} mulch treatments. Under basin system, the 10 t ha^{-1} mulch treatment had 17, 9 and 21 mm more soil water than 0, 2 and 4 t ha^{-1} treatments. This can be due to the effect of 10 t ha^{-1} mulch cover being able to protect the soil from solar radiation and reduce soil surface evaporation. Hatfield *et al.* (2001) reported that mulching can reduce soil evaporation by 34 to 40 %.

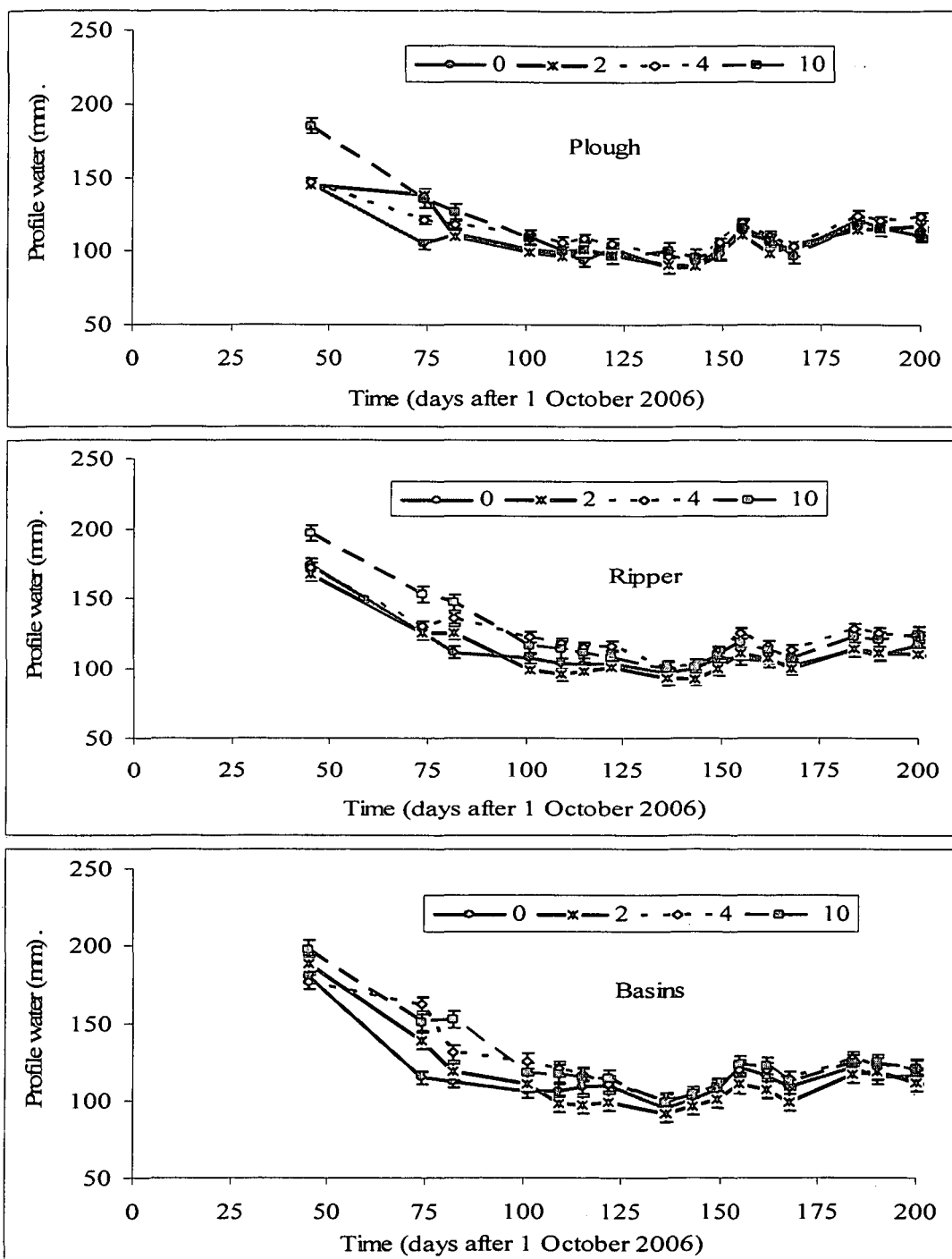


Figure 9b.7. Soil water changes (0 – 0.65 m profile) in response to conventional, ripper and basin tillage systems and four mulching treatments (0, 2, 4 and 10 t ha^{-1}) in the sorghum field during 2006/07 growing season at Matopos Research Station. Error bars represent standard error of means

9b.4.2.4 Water changes in different soil layers under three tillage systems (sorghum phase)

The 0 – 0.15 m soil layer responded to rainfall events more than the deeper layers of the profile (Fig. 9b.8). The same layer also lost soil water faster than the other layers which can be seen by the steeper slope in Figure 9b.8. The 0.15 – 0.25 m layer had the lowest soil water content throughout the growing season in each tillage system in the sorghum field suggesting more extraction of soil water by the sorghum roots from this layer. The results from a study by Sow *et al.* (1997) indicated that most of the roots of sorghum plants are concentrated in the 0.1 – 0.25 m soil layer. At the beginning of soil water measurements, the top soil layer had 36, 41 and 43 mm in the conventional, ripper and basin tillage systems. The 0.15 – 0.25, 0.25 – 0.35 and 0.35 – 0.45 m soil layers had similar water content at the first day of measurements (day 45) long before planting. The 0 – 0.15 m soil layer was recharged in all tillage systems between days 136 (13 February) and 162 (11 March) following 59 mm of rain received. The same soil layer was further recharged in all tillage systems between days 168 (17 March) and 184 (2 April) following 86 mm accumulated between these two dates. Under the three tillage systems the 0.15 – 0.25 m soil layer was also recharged between days 168 (17 March) and 184 (2 April).

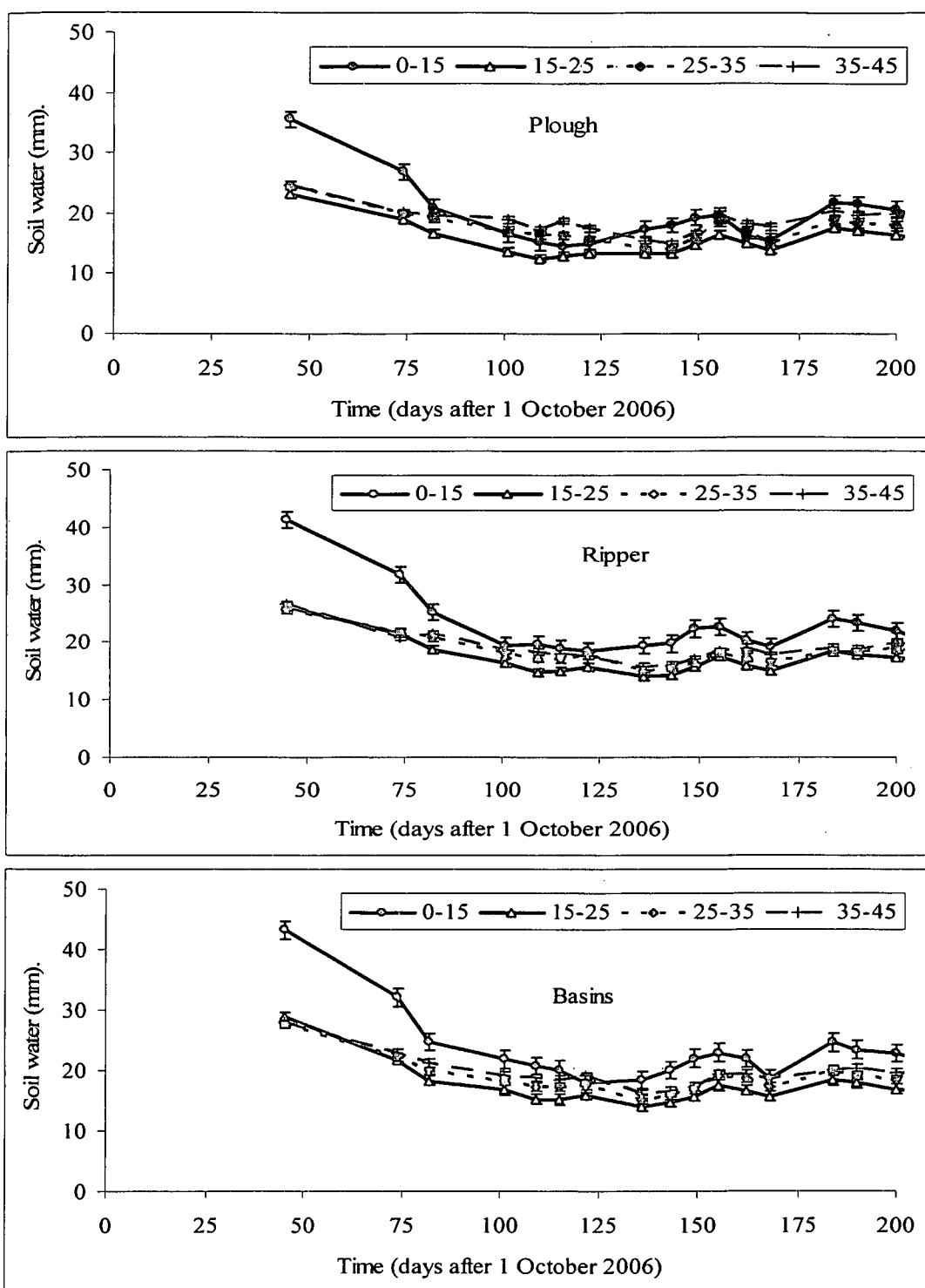


Figure 9b.8. Average changes in equivalent soil water depth in different layers of a clay soil under three tillage systems (conventional, ripper and basin) in sorghum field at Matopos Research Station during 2006/07 growing season. Error bars indicate standard error of the means

9b.4.3 Crop performance

9b.4.3.1 Cowpea and sorghum plant stands

In the 2005/06 season planting basins had a higher ($P = 0.035$) plant stand than the ripper and conventional ploughing tillage treatments (Table 9b.1). In the drier 2006/07 season, there was better cowpea establishment in the ripper tillage system compared to the basin and conventional systems. There was rodent attack before cowpea crop emergence particularly in the basin system. The rodent damage on cereal crops grown in planting basins has also been observed by some smallholder farmers practicing conservation farming in semi-arid districts of Zimbabwe. Some smallholder farmers have devised rodent traps in an effort to curb the challenge (Plate 9b.1). Although the level of mulching had no significant influence on cowpea crop establishment, over the two seasons there was a trend of decreasing plant stand as the mulch cover rate was increased from 4 to 8 and 10 tha^{-1} (Table 9b.1). Soil water content was adequate for good cowpea crop establishment in both 2005/06 and 2006/07 seasons. Sorghum crop stand was lower ($P = 0.078$) under the basin system than the conventional ploughing and ripper systems (Table 9b.2). There was serious attack by rodents in the basin system at crop establishment stage compared to the conventional ploughing and ripper systems.

Table 9b.1. Effect of tillage method and mulch cover on cowpea plant stand two weeks after planting (plants m⁻²) on a red clay soil at Matopos Research Station

Treatment	2005/06	2006/07	Across seasons
Tillage method			
Plough	4.5	2.1	3.3
Ripper	4.5	4.0	4.2
Planting basins	6.3	2.9	4.6
Lsd _{0.05}	1.3	1.5	0.57
Mulch (tha⁻¹)			
0	5.1	3.4	4.3
0.5	5.4	3.3	4.4
1	5.4	3.2	4.3
2	4.8	3.2	4.0
4	5.3	3.2	4.3
8	4.7	2.5	3.6
10	5.0	2.4	3.7
Lsd _{0.05}	0.81	1.1	0.70
CV (%)	17	37	28



Plate 9b.1. A 10 litre bucket half filled with water being used as a rodent trap in a groundnut field in Gokwe district of Zimbabwe

Table 9b.2. Effect of tillage system and mulch treatment on sorghum stand two weeks after planting (plants m⁻²) on a red clay soil at Matopos Research Station

Treatment		2006/07
Tillage	Plough	2.1
	Ripper	2.0
	Basin	1.0
	Lsd _{0.05}	0.43
Mulch (t ha ⁻¹)	0	1.6
	0.5	1.6
	1	1.7
	2	1.7
	4	1.7
	8	1.9
	10	1.6
	Lsd _{0.05}	0.20
	CV (%)	12

9b.4.3.2 Cowpea and sorghum yields

During the relatively wet 2005/06 growing season (832 mm) the tillage and mulch treatments had no significant ($P > 0.05$) influence on grain production from the cowpea phase 1. However, in the 2006/07 season which had below-average rainfall (465 mm), there was significantly ($P = 0.003$) lower grain yield for the cowpea phase 2 in the conventional system, compared to yields obtained from the ripper and planting basin tillage treatments (Table 9b.3). This lower yield is attributed to the fact that the conventional tillage treatment for the cowpea phase 2 was planted 16 days after planting in the ripper and basin systems because the clay soil at Matopos was too wet to plough. In contrast to the 2005/2006 cowpea phase 1 yields, in the dry season 2006/07 the cowpea phase 2 grain yields were significantly ($P = 0.021$) affected by mulch cover (Table 9b.3). The highest yields were recorded for the 4 t ha⁻¹ mulch cover (Table 9b.3), which gave an average 228 kg ha⁻¹ more grain than the 8 t ha⁻¹ mulch treatment, and 221 kg ha⁻¹ than for the 10 t ha⁻¹. The lower cowpea yields obtained at 8 and 10 t ha⁻¹ mulch

cover can be attributed to inferior plant stand recorded under these two mulch treatments (Table 9b.1). The two-way interaction of tillage system and mulch cover had no significant ($P > 0.05$) influence on cowpea grain production during either 2005/06 or 2006/07 growing seasons.

Table 9b.3. Cowpea grain yield responses (kg ha^{-1}) averaged across three tillage systems and seven mulch levels at Matopos Research Station during 2005/06 and 2006/07 growing seasons

Treatment	2005/06	2006/07	Across seasons
Tillage method			
Plough	1 841	288	1 064
Ripper	1 938	553	1 245
Planting basins	1 196	543	870
Lsd _{0.05}	1 171	100	622
Mulch (tha^{-1})			
0	1 732	403	1 067
0.5	1 564	423	993
1	1 875	440	1 157
2	1 474	564	1 019
4	1 800	616	1 208
8	1 686	388	1 037
10	1 479	395	937
Lsd _{0.05}	639	154	319
CV (%)	40	35	48

Across the season comparison revealed that tillage and mulch cover had no significant influence on cowpea yield (Table 9b.3). However, the season had a significant ($P < 0.001$) effect on cowpea yields achieved on the clay soil. Cowpea yield differences between 2005/06 and 2006/07 season can be attributed to differences in rainfall pattern observed at Matopos during the two seasons (Figs. 9b.1 and 9b.3). The two long dry spells recorded in January 2007 negatively impacted on cowpea yields achieved from each tillage system. Delayed planting in the conventional system in 2006/07 season also

resulted in lower cowpea yields in the system compared to the ripper and basin systems as the leaf area had not developed full canopy.

The tillage system had a significant influence on sorghum grain ($P = 0.014$) and stover ($P = 0.018$) production (Table 9b.4). The lowest yields were observed under the planting basin system, with the ripped plots yielding 600 kg ha^{-1} , and conventionally tilled plots yielding 416 kg ha^{-1} more grain. The rodent attack in the basin system of the sorghum phase was more severe than in the cowpea phase 2. Ripper and conventional tillage systems also produced $1\,266$ and $1\,186 \text{ kg ha}^{-1}$ more stover than planting basins. The measured plant stand in planting basin was 43 and 45 % of plant stands achieved in the conventional and ripper tillage systems and attributed to the lower yields produced. Therefore, as the results were influenced by an external factor of rodents, they cannot be used to assess the treatment differences. This experiment would need to be repeated before such results can be used in practice. Mulching had no significant effect on sorghum grain production, harvest index or plant stand. However, sorghum stover yield increased ($P = 0.032$) with increase in mulch cover. The highest sorghum stover produced was $4\,481 \text{ kg ha}^{-1}$ and was achieved at 8 t ha^{-1} mulch treatment. The two-way tillage system and mulch cover interaction had no significant ($P = 0.626$) influence on any of the measured parameters of the sorghum phase crop during 2006/07 growing season.

Table 9b.4. Sorghum yield responses (kg ha^{-1}) averaged across three tillage systems and seven mulch treatments at Matopos Research Station during 2006/07 growing season

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index
<i>Tillage</i>			
Plough	2 005	4 207	0.32
Ripper	2 189	4 287	0.34
Basins	1 589	3 021	0.32
Lsd _{0.05}	311	774	0.055
<i>Mulch</i>			
0	1 756	3 477	0.34
0.5	1 764	3 416	0.34
1	2 046	3 684	0.32
2	1 844	3 877	0.32
4	1 976	3 794	0.34
8	2 050	4 481	0.31
10	2 059	4 140	0.33
Lsd _{0.05}	376	663	0.044
CV (%)	20	18	14

9b.5 Conclusion

The in-season rainfall distribution had a strong influence on cowpea and sorghum yields achieved during 2005/06 and 2006/07 seasons. Dry spells lasting 14 to 16 days negatively impacted on cowpea and sorghum yields as these dry spells coincided with the vegetative and reproductive stages of the crops. Delayed planting of cowpea due to unfavourable soil conditions resulted in lower cowpea yields in the conventional system compared to the basin and ripper systems due to lower leaf area at peak radiation. Planting basin and ripper systems offered an opportunity for timely planting in both seasons resulting in higher cowpea yields particularly in the 2006/07 season which had below average rainfall. Soil water dynamics in the conventional, ripper and basin tillage systems under cowpea and sorghum crops were similar in a clay soil regardless of the rainfall pattern.

Cowpea and sorghum crops both extract soil water predominantly from the 0.15 – 0.25 m depth on a clay soil.

The findings from our study indicate that the wider spacing of the permanent planting positions in the basin and ripper systems does not compromise the yields of cowpea and sorghum crops. This result suggests that grain legumes and small grains can be grown successfully under semi-arid conditions of Zimbabwe using the planting basin and ripper tillage techniques. The basin and ripper systems can give even higher cowpea and sorghum yields than a well managed conventional ploughing system in years with below and above average rainfall pattern as observed in 2005/06 and 2006/07 seasons. However, rodent attack in the basin system poses a big challenge for successful cropping especially in seasons with below average rainfall. In drought years mulching improves cowpea yields with 2 and 4 tha^{-1} giving similar yields. Higher mulch levels of 8 and 10 tha^{-1} , which are unachievable under the current smallholder conditions, suppress cowpea crop establishment, and subsequently lower yields, so should not be recommended anyway. Smallholder farmers in semi-arid southern can target 2 tha^{-1} mulch cover if crop residues are available.

CHAPTER 9c

Cumulative Effects of Minimum Tillage, Mulching and Rotation on Selected Soil Properties and Maize Yield on a Clayey Soil in Semi-Arid Southern Zimbabwe

9c.1 Introduction

Minimum tillage, mulching and crop rotation change soil conditions through modification of physical, chemical and biological properties (Arshad *et al.*, 1999; Dexter, 2004). Positive changes normally occur in soil organic carbon content (Halvorson *et al.*, 2002), soil physical properties such as bulk density and porosity (Arshad *et al.*, 1999), and microbial biomass and activities (Salinas-Garcia *et al.* 1997). Mulching combined with minimum tillage is effective in reducing surface runoff, maintaining soil structure, conserving soil water and adding organic matter to the soil (Liebig *et al.*, 2004; Glab and Kulig, 2008).

The widespread promotion of conservation agriculture (CA) practices has shown significant cereal yield increases on smallholder farms in semi-arid districts of Zimbabwe (Nyagumbo, 2007; Twomlow *et al.*, 2008a). While information on crop yield benefits of conservation agriculture practices continues to be generated, there is a need to assess the other benefits a farmer could derive from adopting CA practices. This is particularly crucial for smallholder farms where farming takes place on fragile and highly degraded soils. Conservation agriculture practices, it is hypothesized, will improve soil fertility, infiltration of rainwater, soil water storage and prolong the period of soil water

availability to crops (Nyagumbo, 2007). This will in turn improve crop productivity from both the soils and limited rainfall received during cropping period.

9c.2 Objectives

The main objective of this study was to assess improvements in soil properties following different periods of practicing conservation agriculture on a clay soil. The specific objectives were to determine the cumulative effect of minimum tillage, mulching, crop rotation and period of exposure to CA practices on the following:

- (1) soil organic carbon content;
- (2) soil bulk density;
- (3) infiltration; and
- (4) maize yield.

9c.3 Materials and Methods

9c.3.1 Experimental design and layout

The experiment was set up on four fields from the 2004/05 till the 2007/08 growing season as outlined in Chapter 3. The same fields and some of the plots used for chapters 9a and 9b were used for assessing changes in soil properties. Crops grown in each field and their sequence are outlined in Table 9c.1.

Table 9c.1. Experimental fields used and crops grown in each field from 2004/05 to 2007/08 seasons at Matopos Research Station

Field number	Period under CA (#seasons)	Season(s) field was used	Crop sequence	Tillage system used all years	Mulch rate (tha ⁻¹)
1	1	2007/08	Maize (M)	Plough, ripper, basins	0, 4 and 10
2	2	2006/07 and 2007/08	Maize – maize (MM)	Plough, ripper, basins	0, 4 and 10
3	3	2005/06, 2006/07 and 2007/08	Maize – cowpea – maize (MCM)	Plough, ripper, basins	0, 4 and 10
4	4	2004/05, 2005/06, 2006/07 and 2007/08	Maize – cowpea – sorghum – maize (MCSM)	Plough, ripper, basins	0, 4 and 10

9c.3.2 Soil sampling and measurements taken

In planting basin system measurements were made within the basin and in the space between two basins in the same row. In the ripper system measurements were made within the ripline and at the inter-row space. In the conventional ploughing system measurements were made along the planting row. In this chapter the following abbreviations are used to denote the tillage treatments; CP (plough) – conventional ploughing, BRL – between riplines, RL – within riplines, BB – between planting basins and WB – within planting basin. Soil samples for organic carbon and bulk density analysis were collected from 24 to 28 March 2008. Infiltration measurements in all four fields were done from 31 March to 4 April 2008.

9c.3.2.1 Organic carbon

In each plot, soil samples were collected from 0 - 0.10 m and 0.10 – 0.20 m depths using steel cores measuring 0.03 m internal diameter by 0.95 m length. Three sampling positions were used in each plot for each soil depth. A composite soil sample for each soil depth was made by mixing soil samples collected from the three sampling positions. A sub-sample from each treatment was packed into khaki pockets and taken to the laboratory for air drying. After air drying the soil was sieved through a 2 mm sieve before doing chemical analysis for organic carbon using the Sommer's method (Anderson and Ingram, 1993).

9c.3.2.2 Bulk density

Steel cores measuring 0.05 m diameter and 0.05 m height were used to collect soil samples from each tillage x mulch treatment combination in all four fields. Undisturbed soil samples were collected in duplicates from each plot at 0.05 m depth interval up to 0.30 m depth. The samples were oven dried at 105°C for 48 hours before measuring weight of the dried samples and calculating bulk density at each soil depth according to the procedure outlined by Anderson and Ingram (1993).

9c.3.2.3 Infiltration, hydraulic conductivity and sorptivity

Infiltration measurements were conducted using a minidisk infiltrometer produced by Decagon Devices (2007) (Plate 9c.1). The minidisk infiltrometer consists of three major components namely sintered steel disc of 0.022 m radius at the base of infiltrometer, a 95 mm water reservoir and a bubble chamber. Infiltration runs were conducted in duplicate

for each tillage x mulch treatment combination for all four experimental fields. Particular care was taken during the preparation of the soil surface before each infiltration run. A relatively flat surface was identified in each tillage x mulch treatment combination and all residues of weeds and maize were removed from the identified soil surface. The micro-topography of the surface was leveled with a spatula in order to ensure adequate horizontal contact between soil surface and the sintered steel base of the infiltrometer. Infiltration measurements were made at a single supply head of -20 mm as recommended by the manufacturer for clay soils (Decagon Devices, 2007) and it took 10 to 15 minutes to reach a steady state flow from the infiltrometer. Changes in water volume in the water reservoir of the infiltrometer were recorded at 30 s interval.

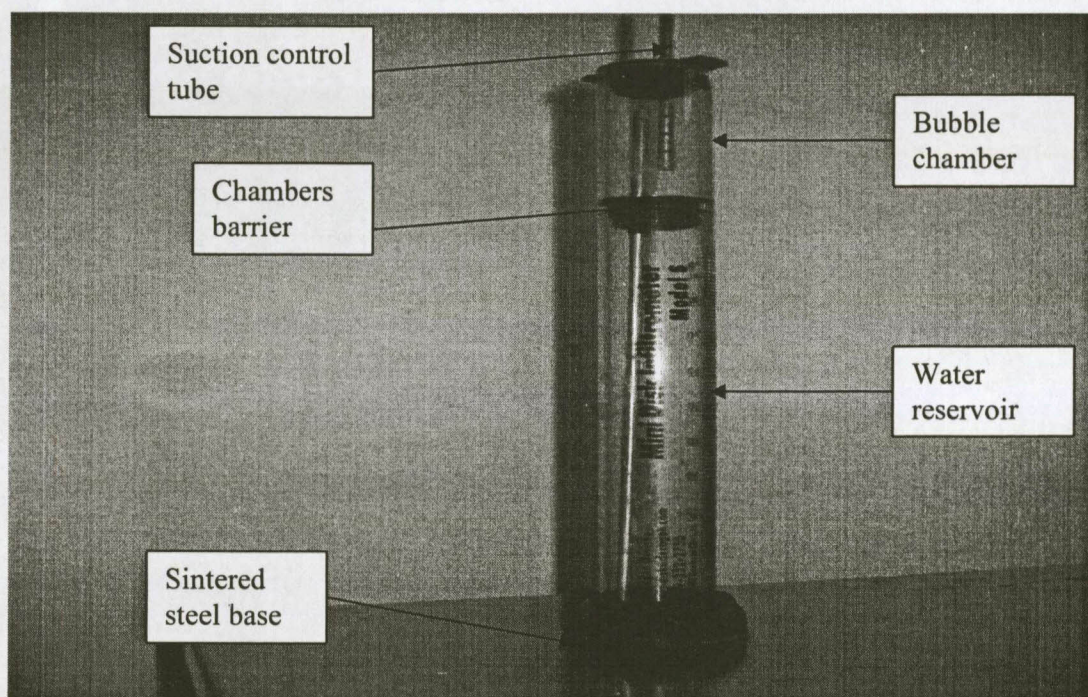


Plate 9c.1. Minidisk infiltrometer used for infiltration measurements

Infiltration results were fitted to the following equations in order to calculate hydraulic conductivity and capillary sorptivity. The procedure followed in our calculations of hydraulic conductivity and sorptivity was proposed by Zhang (1997) in Decagon Devices (2007).

$$I = C_1 + C_2 \sqrt{t} \quad \text{Equation 9c.1}$$

where I is cumulative infiltration (mm), C_1 (ms^{-1}) is related to hydraulic conductivity, C_2 ($\text{ms}^{-0.5}$) is related to soil sorptivity, and t is time taken for each infiltration run. The hydraulic conductivity (K) of the soil is then computed from

$$K = C_1 / A \quad \text{Equation 9c.2}$$

where C_1 is slope of the curve of cumulative infiltration vs. square root of time, and A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk. The A is computed from

$$A = [(11.65(n^{0.1} - 1)) \exp.[2.92(n-1)\alpha h_0]] / (\alpha r_0)^{0.91} \quad \text{Equation 9c.3}$$

where n and α are the van Genuchten parameters for the soil, r_0 is disk radius, h_0 is the suction at the disk surface. Values of A (van Genuchten parameter for a 2.2 cm radius minidisk infiltrometer) computed for the minidisk infiltrometer are given in Table 9c.2.

C_2 which gives the soil's sorptivity is computed from

$$C_2 = (I - C_1 t) / \sqrt{t} \quad \text{Equation 9c.4}$$

9c.3.2.4 Soil water content before and after infiltration

Soil water content at 0 – 0.10 and 0.10 - 0.20 m depths was measured in each plot using a capacitance probe before infiltration runs were conducted. Soon after each infiltration run a soil sample was taken from 0 – 0.10 m depth on the position where the base of the

infiltrometer was sitting. The soil samples were weighed and then oven dried at 105°C for 48 hours and gravimetric water content was determined using a procedure outlined by Anderson and Ingram (1993). Gravimetric water content was converted to volumetric water content using measured bulk density for each soil layer.

Table 9c.2. van Genuchten parameters for 12 textural classes and A values for 2.2 cm disk radius and suction values from 0.5 to 6.0 cm (Adapted from Carsel and Parrish, 1988)

			h_0						
			-0.5	-1.0	-2.0	-3.0	-4.0	-5.0	-6.0
Texture	α	n	A						
Sand	0.145	2.68	2.9	2.5	1.8	1.3	0.9	0.7	0.5
Loamy sand	0.124	2.28	3.0	2.8	2.5	2.2	1.9	1.6	1.4
Sandy loam	0.075	1.89	4.0	4.0	4.0	4.0	4.0	4.1	4.1
Loam	0.036	1.56	5.6	5.8	6.4	7.0	7.7	8.4	9.2
Silt	0.016	1.37	8.1	8.3	8.9	9.5	10.1	10.8	11.5
Silt loam	0.020	1.41	7.2	7.5	8.1	8.7	9.4	10.1	10.9
Sandy clay loam	0.059	1.48	3.3	3.6	4.3	5.2	6.3	7.6	9.1
Clay loam	0.019	1.31	6.0	6.2	6.8	7.4	8.0	8.7	9.5
Silt clay loam	0.010	1.23	8.1	8.3	8.7	9.1	9.6	10.1	10.6
Sandy clay	0.027	1.23	3.4	3.6	4.2	4.8	5.5	6.3	7.2
Silty clay	0.005	1.09	6.2	6.3	6.5	6.7	6.9	7.1	7.3
Clay	0.008	1.09	4.1	4.2	4.4	4.6	4.8	5.1	5.3

Where n and α are the van Genuchten parameters for a given soil texture, h_0 is the suction at the disk surface.

9c.3.2.5 Maize crop performance

Plant counts were taken two weeks after planting. At harvest grain and stover (above-ground biomass minus grain) yields were estimated from a net plot consisting of five middle rows with a running length of 6 m. The weight of cobs and stover from the netplot of each treatment were determined in the field before taking sub-samples for moisture correction. Grain and stover samples were dried at 60°C for 48 hours for moisture adjustment. The maize shelling percentage was determined for each treatment to convert

cob weight into grain and core weights. Grain weight was converted to a per hectare basis at 12.5 % moisture content as final grain yield following procedure outlined in Chapter 3.

9c.3.3 Statistical analysis

All statistical analysis was performed using Residual Minimum Likelihood Method (REML). The REML method has the capability of analyzing data with an unbalanced design. The tillage treatment in our study was unbalanced because ripper and basin systems had two sampling positions each while plough had only one level. Tillage, mulch and field and their interactions formed the fixed model while each replicate for the measurements was applied as the random model. Soil water data collected before and after infiltration were analyzed using the General Analysis model of ANOVA. Genstat Discovery Edition 3 (www.vsnl.co.uk) was used for statistical analysis. Then the least significant difference (Lsd) at 5 % significance level was used to compare treatment means.

9c.4 Results and Discussion

9c.4.1 Soil organic carbon

Soil organic carbon content in the 0 – 0.2 m depth measured in each field at the end of 2007/08 growing season is given in Table 9c.3. There was a significant ($P = 0.042$) increase in soil organic carbon content in CP and WB with increase in period of exposure to minimum tillage, mulching and rotation (Table 9c.3). The maize-cowpea-maize (field 3) and maize-cowpea-sorghum-maize (field 4) fields had higher ($P = 0.042$) organic carbon content than the maize (fields 1) and maize-maize (field 2) fields in CP, as well as

between and within the planting basin. The lowest organic carbon content was 0.67 % observed in CP tillage system at 0 tha^{-1} mulch level following only one year of CA treatments maize field (field 1). The maize-cowpea-maize (field 3) and maize-cowpea-sorghum-maize (field 4) fields benefited from cowpea stover that was left on the surface after harvesting at the end of 2005/06 and 2006/07 growing seasons (Chapter 9b). In fields 1 and 2 only manure, mulching material and weeds contributed towards organic carbon during 2006/07 and 2007/08 seasons.

Table 9c.3. Effect of tillage and period of exposure to CA practices averaged across three mulch levels (0, 4 and 10 tha^{-1}) on soil organic carbon content (%) of a clay soil at Matopos Research Station

Tillage & location	Field number and crop sequence			
	1 (M)	2 (MM)	3 (MCM)	4 (MCSM)
CP	0.67	0.71	0.90	1.00
BRL	0.97	0.92	0.91	0.90
RL	0.98	0.90	0.92	0.95
BB	0.76	0.80	0.90	0.83
WB	0.93	0.90	1.13	1.06

Lsd_{0.05} = 0.19; CV = 21 %

There was a higher ($P < 0.05$) organic carbon content in the 0- 0.10 m layer than 0.10 – 0.20 m under the ripper and planting basin systems regardless of sampling position (Fig. 9c.1). In the top 0:10 m layer, there was more organic carbon within planting basin than all other tillage treatments. More organic carbon within planting basin can be attributed to manure that was applied in the basins every year. Along the rip line manure was dribbled each year with the area between rip lines and basins receiving no manure in any of the seasons. Studies by Belder *et al.* (2007) also showed an increase in organic carbon in basins following three seasons of practicing conservation farming on smallholder farms.

Carter (1996) observed organic matter increase in 0 – 0.10 m soil layer with use of reduced tillage after nine years of experimentation. Similar organic carbon content was observed in the 0 – 0.10 and 0.10 – 0.20 m layers under the conventionally ploughed system. The ploughing operation incorporated the surface applied manure and some of the maize residue applied as mulch. As ploughing was conducted in subsequent seasons manure and decomposing maize residues were probably distributed evenly within the 0 – 0.20 m plough layer.

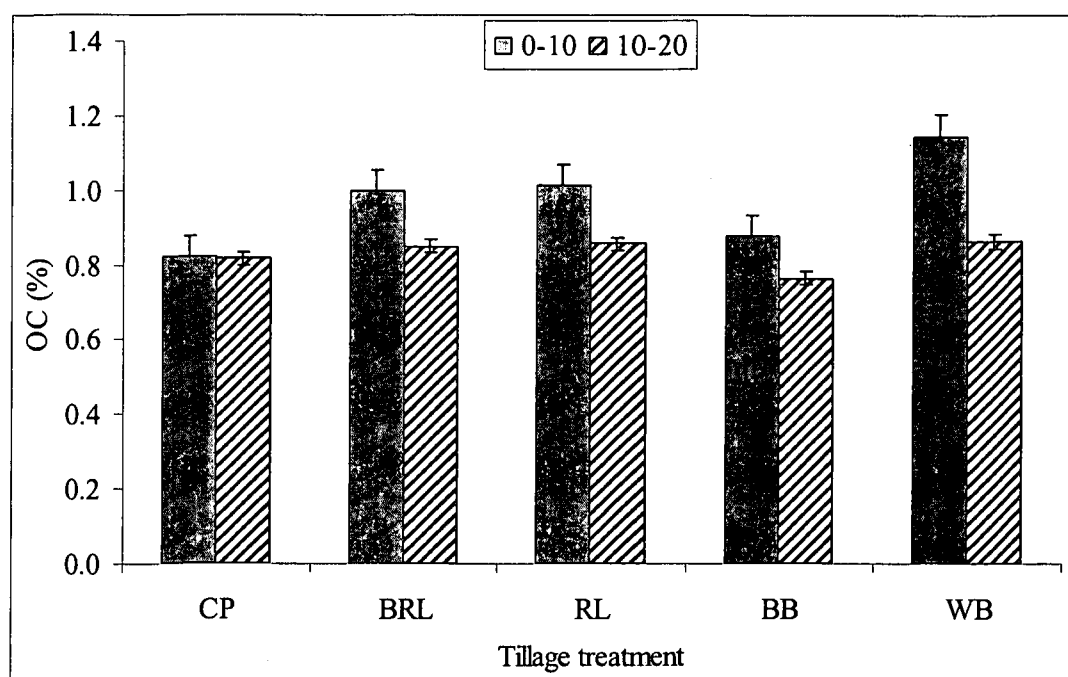


Figure 9c.1. Effect of tillage and soil depth on organic carbon content (%) of a red clay soil at Matopos Research Station. Error bars represent standard error of means

9c.4.2 Soil bulk density

In the one-season maize field (M), the lowest soil bulk density was recorded in the ripline while the area between planting basins had the most compacted soil (Table 9c.4). In this same field, soil bulk density at 0 and 4 tha^{-1} mulch treatment was similar but lower than

soil bulk density observed at 10 tha^{-1} mulch cover in the CP system. In the ripper tillage system, 10 tha^{-1} mulch treatment had lower soil bulk density compared to 0 and 4 tha^{-1} mulch cover in the ripline. Soil bulk density was similar under the three mulch treatments between the riplines. In the planting basin (WB), soil bulk density was lower under 4 tha^{-1} than 0 and 10 tha^{-1} mulch treatments. The 0 and 10 tha^{-1} mulch treatments had similar soil bulk density in the planting basin. In the area between planting basins, the soil was more compacted at 0 tha^{-1} mulch treatment than at 4 and 10 tha^{-1} mulch cover.

Table 9c.4. Effect of tillage, mulching and year interaction on soil bulk density of a red clay soil at Matopos Research Station

Mulch (tha^{-1})	Tillage	Field number and crop sequence			
		1 (M)	2 (MM)	3 (MCM)	4 (MCSM)
0	CP	1.51	1.55	1.57	1.50
	RL	1.46	1.57	1.47	1.44
	BRL	1.45	1.51	1.52	1.52
	WB	1.57	1.59	1.48	1.48
	BB	1.63	1.55	1.48	1.50
4	CP	1.51	1.62	1.54	1.48
	RL	1.48	1.53	1.45	1.43
	BRL	1.48	1.54	1.54	1.45
	WB	1.44	1.55	1.50	1.46
	BB	1.54	1.59	1.51	1.49
10	CP	1.63	1.66	1.51	1.50
	RL	1.39	1.46	1.46	1.36
	BRL	1.46	1.54	1.52	1.46
	WB	1.58	1.47	1.50	1.41
	BB	1.55	1.62	1.49	1.47

Lsd_{0.05} = 0.096; CV = 7.2 %

In the field with two seasons of conservation agriculture practices and monocrop maize (MM), the least compacted soil was in the ripline regardless of the mulch treatment (Table 9c.4). The conventional tillage system had the most compacted soil followed by

the area between planting basins. In the conventional system, 4 and 10 tha^{-1} mulch treatments had similar soil bulk densities (1.62 and 1.66 gcm^{-3}) with the 0 tha^{-1} mulch treatment having lower soil bulk density (1.55 gcm^{-3}) compared to the mulched plots. In the ripline and planting basin, soil bulk density decreased with increase in the quantity of mulch applied. However, in the area between riplines, soil bulk density was similar under 0, 4 and 10 tha^{-1} mulch treatments. Soil bulk density was higher at 10 tha^{-1} mulch treatment than at 0 and 4 tha^{-1} mulch cover on the area between planting basins.

In the field with three seasons under conservation agriculture with cowpea rotation (MCM), the least compacted soil was also observed in the ripline while the conventional system had the most compacted soil. In the conventional system, soil bulk density decreased with increase in the amount of mulch cover applied. In the ripper system, the three mulch treatments had similar effect on the measured soil bulk density in the ripline. In the area between riplines, 0 and 10 tha^{-1} mulch had similar effect on soil bulk density and the 4 tha^{-1} mulch cover had higher soil bulk density than the other two mulch treatments. In the planting basin, 4 and 10 tha^{-1} mulch treatments had a similar effect on soil bulk density. In the area between planting basins, the soil under 4 tha^{-1} mulch cover was more compacted compared with soil under 0 and 10 tha^{-1} mulch treatments.

In the field exposed to conservation agriculture practices for four seasons with cowpea and sorghum in rotation with maize (MCSM), the soil in the ripline was the least compacted followed by soil in the planting basin. The conventional system and the area between planting basins had the most compacted soil. In the conventional system, 0 and

10 tha^{-1} mulch treatments had similar soil bulk density (1.5 gcm^{-3}) and the 4 tha^{-1} mulch cover had 1.48 gcm^{-3} . In the ripper system, soil bulk density decreased with increase in mulch cover applied in the ripline. In the area between riplines, the soil under 4 and 10 tha^{-1} mulch cover was less compacted compared with the soil in unmulched plots. In the basin system, soil bulk density decreased with increase in the quantity of mulch cover applied. Soil in the planting basin was less compacted than the soil from the area between basins. The comparison across the four fields used in the 2007/08 season indicates that soil bulk density decreased when conservation agriculture practices had been implemented a longer period of time. The most noticeable decrease in soil bulk density was measured in the ripline and within the planting basin.

The reduced bulk density between basins and rip lines at 4 and 10 tha^{-1} mulch in fields 3 and 4 could be attributed to the combined effect of minimum tillage and mulching on modifying soil physical properties. Minimum tillage and the decomposing maize residues probably promoted soil aggregation as reported elsewhere by Hadas *et al.*, (1994) and Mulumba and Lal (2008). As soil aggregation takes place more pores develop and findings from a study by Glab and Kulig (2008) revealed a significant increase in porosity within the top 0.10 m soil layer with reduced tillage and mulching. Soil bulk density was generally lower in field 1 (M) than field 2 (MM) across all mulch levels and tillage methods. This could be attributed to the fact that field 1 (M) was fallow during 2006/07 cropping season. At the start of 2005/06 season field 1 was tractor ploughed and maize was grown during that season. During 2006/07 season the field lay fallow with

maize stover from 2005/06 season left in the field and it decomposed during the course of 2006/07 season. Then maize for this experiment was planted in 2007/08 season.

Figures 9c.2 and 9c.3 presents soil bulk density variation with respect to soil depth in the four fields exposed to conservation agriculture practices for different number of seasons. After the first season of CA treatments (illustrated by field 1), in the surface soil layer, the ripline the lowest soil bulk density as the soil was disturbed during ripping. Soil bulk density between planting basins in the surface layer is as high as the conventional tillage system. This would be expected as the area between basins has remained unploughed and compaction can also be caused by the movement of people during field operations. In the deeper soil layers (20-30 cm), the highest soil bulk density was measured in the basin tillage system. This shows that the effect of the planting basin on soil disturbance is only confined to the 0-15 cm soil layer.

In the field with two seasons of CA treatments (illustrated by field 2), soil bulk density was similar in the top 15 cm layer within the ripline and planting basin. The area between planting basins had the most compacted soil in the top 5 cm layer and this is attributed to the fact that this area had not been ploughed for two seasons. The conventional system had more compact soil from 10 cm layer and below compared with the other treatments. The high soil bulk density at 25 to 30 cm depth can be attributed to a plough pan that could have developed over the years during ploughing operations before our trial was established.

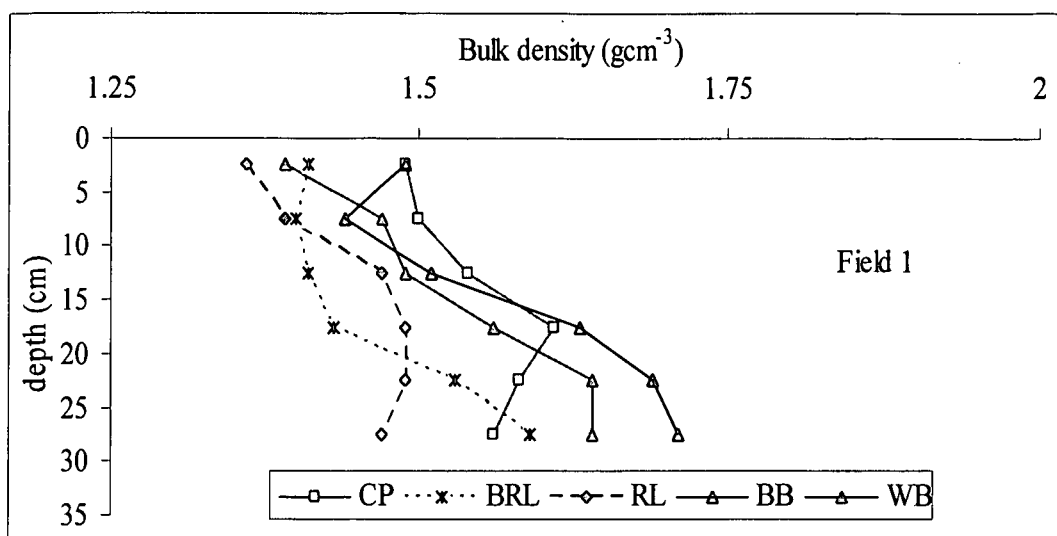


Figure 9c.2. Soil bulk density distribution with respect to soil depth in different tillage treatments in field 1 (first year of CA treatments) at Matopos Research Station

In the field exposed to conservation agriculture for three seasons (Field 3), soil bulk density within ripline and planting basin was lowest and similar in the top 5 cm soil layer. However, from the 10 cm to 25 cm depth, soil in the ripline was the least compacted. As observed in fields 1 (M) and 2 (MM), the lowest soil bulk density in the ripline is attributed to the ripper being able to disturb the soil much deeper than the other tillage treatments. In the planting basin, soil bulk density increased more rapidly from the 10 cm layer to the 15 cm than the other tillage treatments. This is rather unusual as the 0-15 cm soil layer was disturbed three times during the opening of planting basins. As observed in the other two fields, the conventional system had more compacted soil than the other treatments.

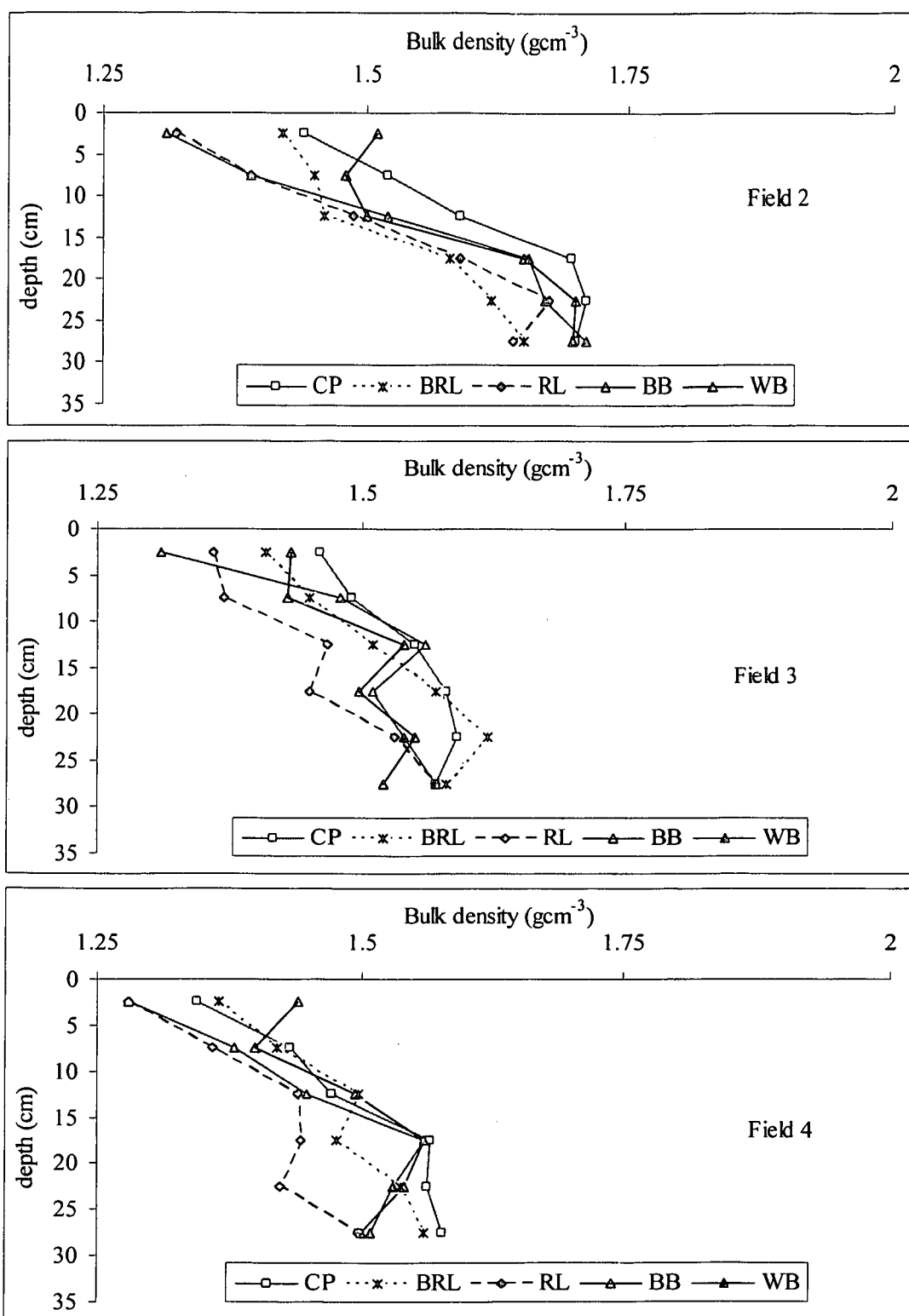


Figure 9c.3. Soil bulk density distribution with respect to soil depth in different tillage treatments and fields at Matopos Research Station

As observed in the other three fields (M, MM and MCM), the least compacted soil in the top 15 cm soil layer was within the ripline and planting basin in a field exposed to conservation agriculture for four seasons (Field 4). Soil bulk density was consistently lower in the ripline in the entire 0-30 cm profile than the other tillage treatments (Fig. 9c.2). In contrast to the ripline, soil bulk density within the planting basin increased in the 15 to 20 cm layers, further highlighting the fact that the basin effect is confined in the top 0-15 cm layer. As observed in fields 1 (M) and 2 (MM), the area between planting basins had the most compacted soil compared with the other treatments.

9c.4.3 Cumulative infiltration

Cumulative infiltration measured under the 0 tha^{-1} mulch treatment in fields 1 (M), 2 (MM), 3 (MCM) and 4 (MCSM) under conventional (CP), within ripline (RL) and within planting basin (WB) tillage treatments is presented in Figures 9c.4 and 9c.5. The highest amount of water infiltrating into the soil was 60 mm recorded in the planting basin from the maize-cowpea-maize field (Field 3). The low soil bulk density observed in the top 5 cm in the planting basin (WB) from field 3 (MCM) (Fig. 9c.3) suggests better porosity and this could have enabled more water to infiltrate into the soil. Under the 0 tha^{-1} mulch treatment, field 1 (M) had the lowest cumulative infiltration measured from the CP system during the 15-minute infiltration run compared with the other three fields. In the ripline, the maize-cowpea-maize field (Field 3) recorded more water infiltrating into the soil than the other fields (Fig. 9c.4 and 9c.5). The low cumulative infiltration in field 1 (M) could be explained by the relatively high initial soil water content. Field 1 (M) had the highest soil water content in the top 0.10 m before infiltration measurements were

conducted. Das and Chopra (1988) state that in some soils, infiltration rate is high if the initial soil water content is low. Field 1 was waterlogged during part of December 2007 and January 2008.

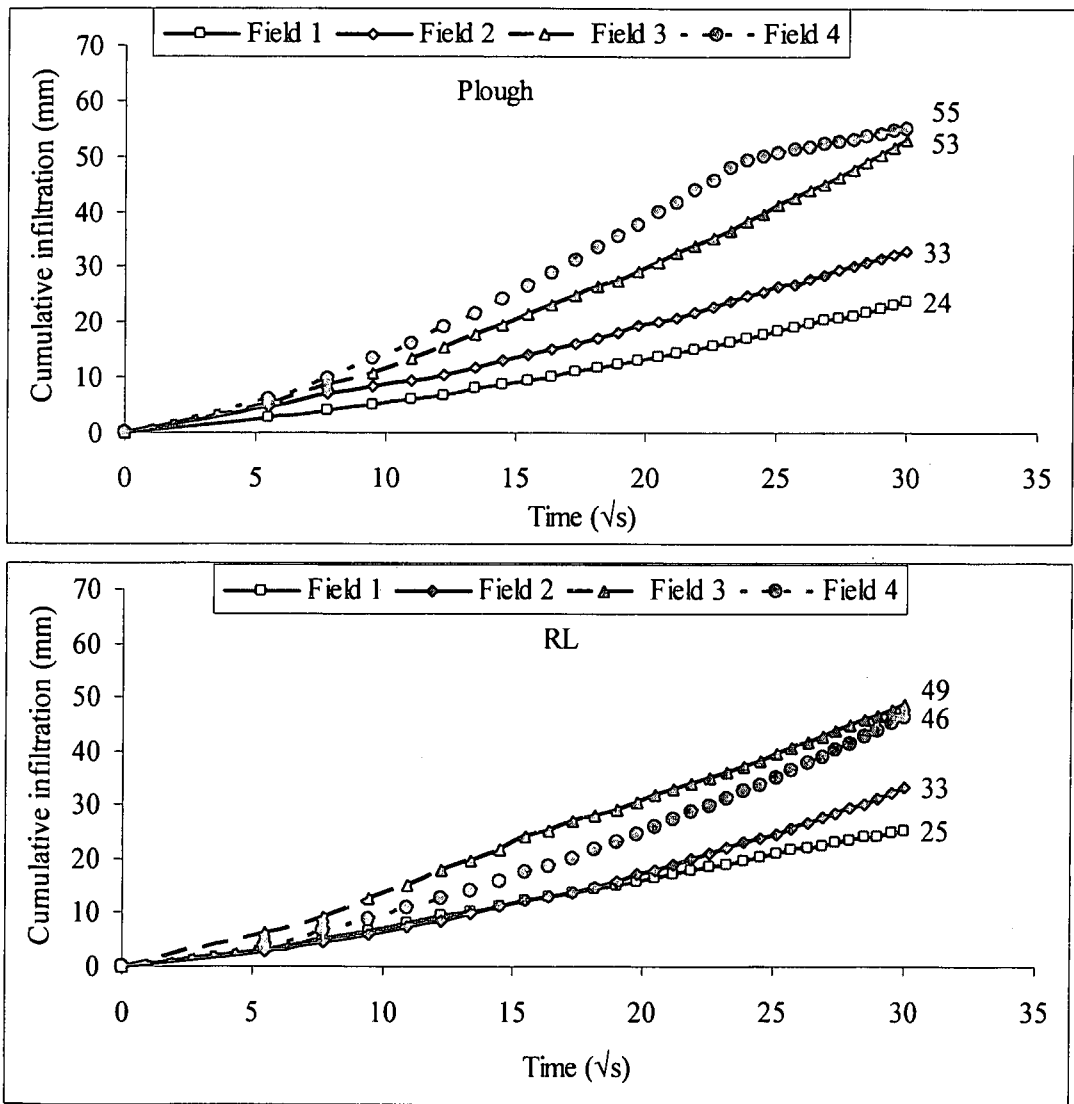


Figure 9c.4. Effect of conventional ploughing and ripper systems, 0 tha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil

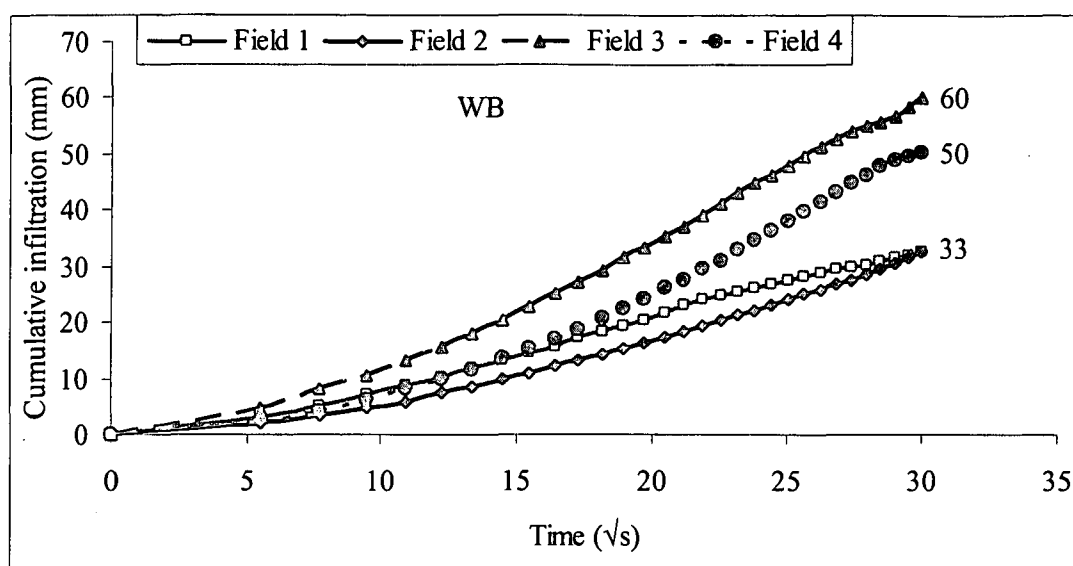


Figure 9c.5. Effect of basin system, 0 tha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil

Under the 4 tha^{-1} mulch treatment, the maize-cowpea-maize field (field 3) had 62 mm of water infiltrating into the soil from the CP tillage treatment (Fig. 9c.6). Within the ripline the maize-cowpea-maize field (field 3) had more water infiltrating into the soil during the 15-minute infiltration run. In contrast, the highest volume of water (47 mm) infiltrating into the soil in the planting basin was recorded from the maize-cowpea-sorghum-maize field (field 4). The high cumulative infiltration in the CP treatment of field 3 (MCM) at 4 tha^{-1} mulch could be linked to high capillary sorptivity observed under this treatment (Table 9c.5). This observation could be explained by the size and orientation of soil pores in field 3 (MCM) in the CP system. Moreno *et al.* (1997) state that if initial soil water content is not significantly different across treatments under consideration, infiltration can be influenced considerably by pore size distribution in the soil matrix. The field with first season of CA treatments (Field 1) had the lowest cumulative infiltration across the tillage treatments and this could be due to low sorptivity of the soil (Table 9c.5).

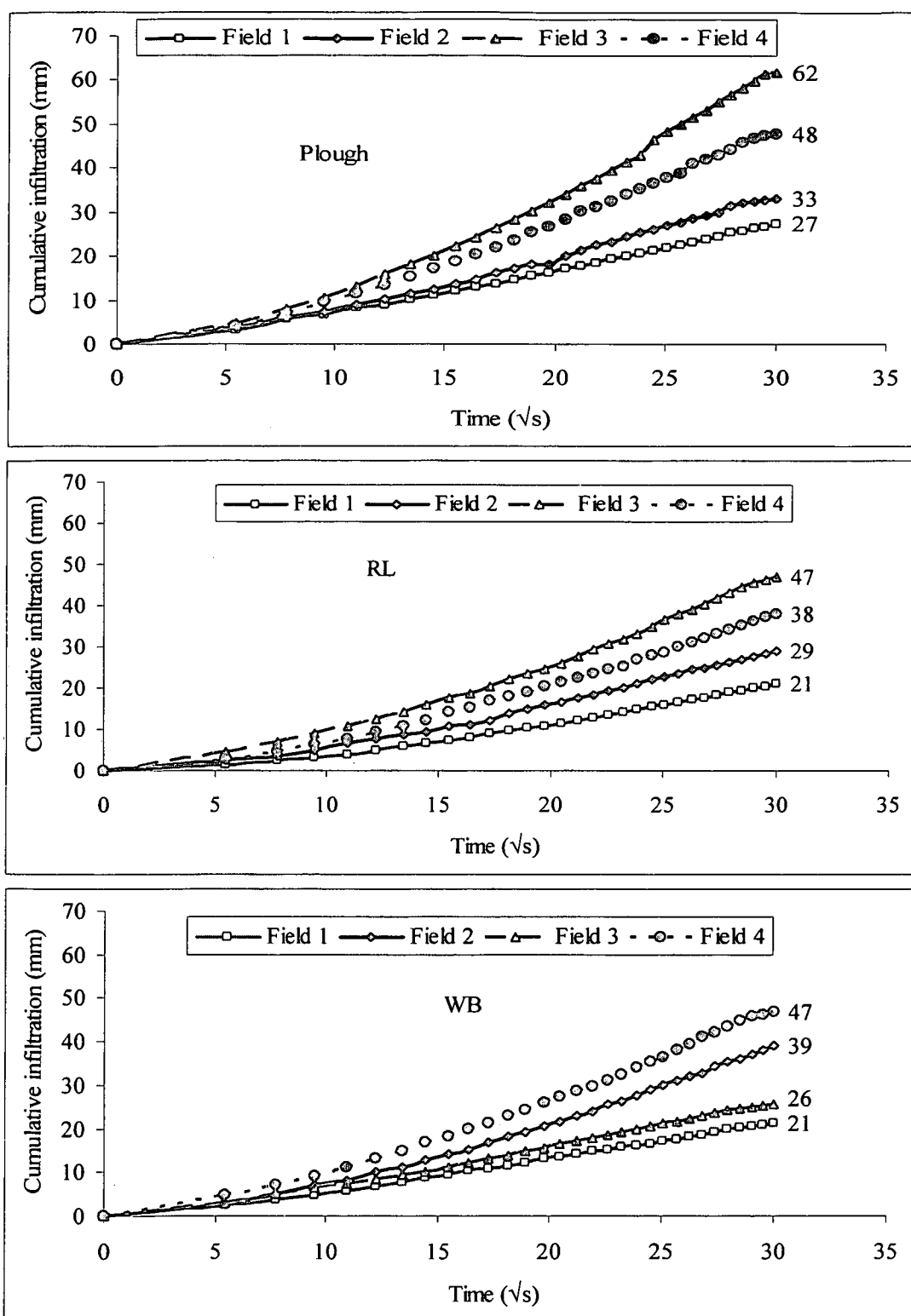


Figure 9c.6. Effect of tillage, 4 t ha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil

Under the 10 tha^{-1} mulch treatment, the maize-cowpea-maize field (Field 3) had the highest cumulative infiltration (62 mm) measured in the planting basin during the 15 minute infiltration run (Fig. 9c.7). The field exposed to CA practices for four seasons (Field 4) had the lowest cumulative infiltration (30 mm) in the CP and within rip line at 10 tha^{-1} mulch treatment. This is at odds with hydraulic conductivity observed in CP and RL in field 4 (Table 9c.5). In field 2, representing maize monocropping, planting basins recorded a lower volume of water infiltrating into the soil than the other tillage treatments. This observation on cumulative infiltration is inconsistent with soil bulk density, hydraulic conductivity and capillary sorptivity results (Tables 9c.4 and 9c.5). Hydraulic conductivity was relatively high in CP and RL tillage treatments (Table 9c.5). Low water absorption in the CP and RL at 10 tha^{-1} could be a result of trapped air within the soil matrix. The advance of water through the soil during infiltration may result in sealing of pathways through which air could escape (Peck, 1969; Azooz and Arshad, 1996). This results in a significant reduction in infiltration rate as water is forced to follow other paths that could be more tortuous.

The mulch treatment had no significant ($P = 0.634$) influence on the amount of water infiltrating into the soil during the 15 minute infiltration run across the four fields. Under the 0 and 10 tha^{-1} mulch treatments, 41 mm of water infiltrated into the soil while 37 mm were recorded at 4 tha^{-1} mulch cover. This observation suggests that water movement through the soil matrix is influenced by soil properties regardless of the level of mulch cover applied.

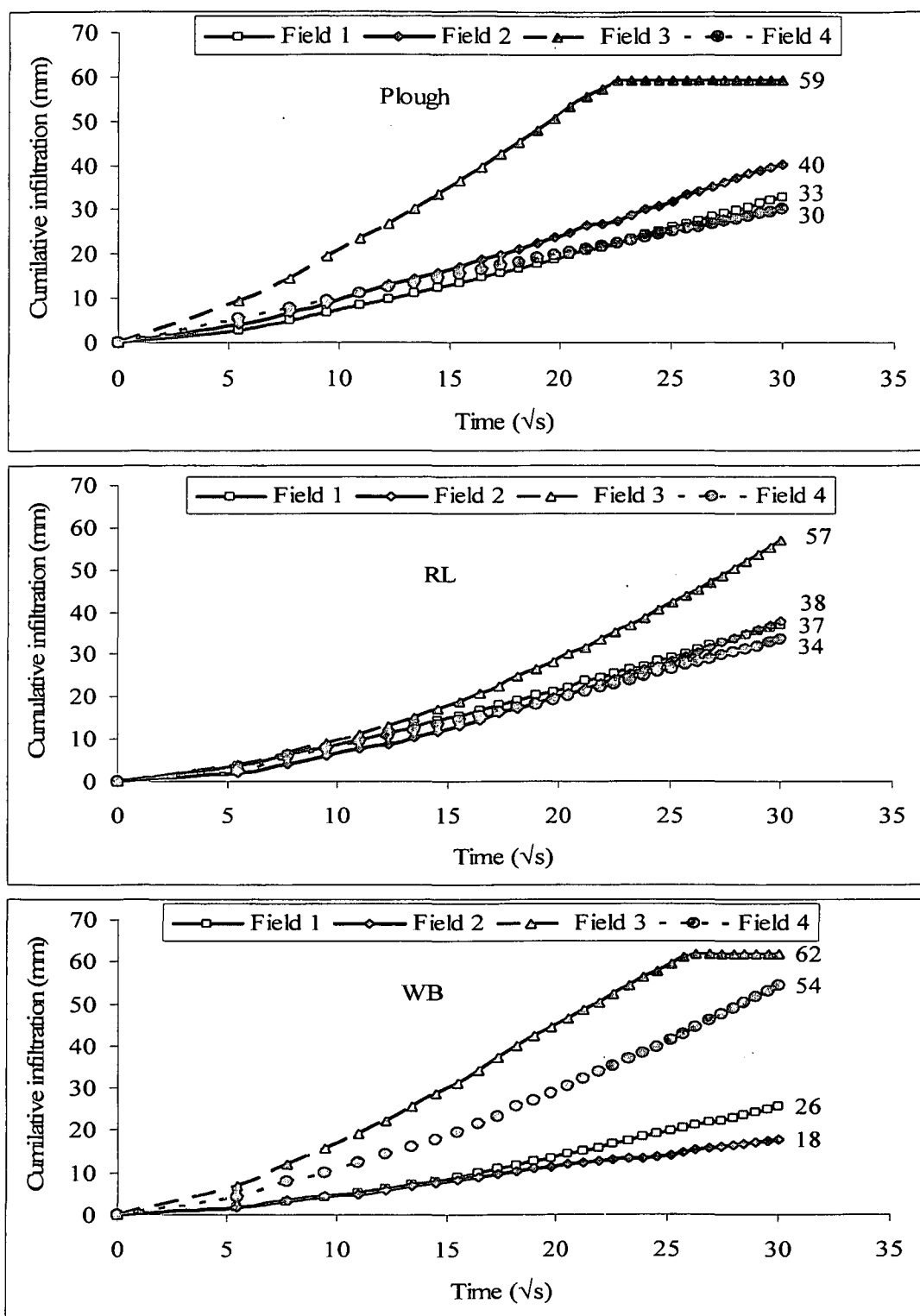


Figure 9c.7. Effect of tillage, 10 t ha^{-1} mulch cover and period of exposure to CA practices on cumulative infiltration of a clay soil

9c.4.4 Hydraulic conductivity and capillary sorptivity

Hydraulic conductivity and capillary sorptivity were significantly ($P < 0.001$) influenced by the three way interaction of mulching, tillage system and period of exposure to CA practices. In the field under CA practices for the first time, conventional system had higher hydraulic conductivity and sorptivity at 0 and 4 tha^{-1} mulch treatments than the other tillage treatments (Table 9c.5). However, at 10 tha^{-1} mulch cover the highest hydraulic conductivity and sorptivity were observed in the ripline from field 1 (M). In the continuous maize monocropping field (Field 2), the measured hydraulic conductivity was higher in the conventional system. In contrast, highest sorptivity was 1.1 $\text{mm}/\sqrt{\text{s}}$ in the planting basin at 0 tha^{-1} mulch, 1.26 $\text{mm}/\sqrt{\text{s}}$ in the ripline at 4 tha^{-1} mulch and 0.93 $\text{mm}/\sqrt{\text{s}}$ between planting basins at 10 tha^{-1} mulch cover.

In the maize-cowpea-maize field (field 3), hydraulic conductivity was higher in the ripline under 0 and 10 tha^{-1} mulch treatments. In the same field, hydraulic conductivity measured in the planting basin was slightly lower than in the ripline under 0 tha^{-1} mulch treatment. Under the 4 tha^{-1} mulch treatment, the CP and BB (between basins) treatment had similar hydraulic conductivity in the maize-cowpea-maize field. The sorptivity was high in the BRL (between riplines) treatment under 0 tha^{-1} mulch cover, in the CP treatment under 4 tha^{-1} and RL (in riplines) under 10 tha^{-1} mulch treatment. In the maize-cowpea-sorghum-maize field (field 4), the soil between planting basins had higher hydraulic conductivity under 4 and 10 tha^{-1} mulch cover. In the unmulched tillage treatments, soil in the ripline had higher hydraulic conductivity compared with other

treatments. Sorptivity was high in the planting basin at each mulch treatment in field 4 (MCSM).

Table 9c.5. Effect of minimum tillage, mulching and period of exposure to CA practices on soil hydraulic conductivity (K) (10^{-3} mms^{-1}) and capillary sorptivity (S) ($\text{mm}/\sqrt{\text{s}}$) of a clay soil at Matopos Research Station

Mulch (tha^{-1})	Tillage	K				S			
		Field number				Field number			
		1	2	3	4	1	2	3	4
0	CP	9.80	3.43	5.00	2.57	1.31	0.73	1.36	0.56
	BRL	3.00	1.98	4.05	3.27	0.78	0.60	1.39	0.84
	RL	4.02	2.00	7.59	3.36	0.43	0.93	1.31	0.95
	BB	3.77	2.32	3.93	1.59	0.65	0.97	0.91	0.84
	WB	6.23	2.02	6.98	2.07	1.13	1.10	0.64	1.06
4	CP	3.46	3.66	4.00	4.84	0.52	0.84	1.39	0.92
	BRL	2.95	2.78	2.93	2.93	0.23	0.51	0.43	0.67
	RL	1.59	2.68	3.09	3.09	0.40	1.26	1.13	0.73
	BB	1.80	1.68	4.00	6.18	0.40	1.07	1.07	0.78
	WB	3.02	3.00	3.48	4.02	0.37	0.71	0.79	0.96
10	CP	3.89	4.98	2.42	4.50	0.59	0.49	0.74	1.09
	BRL	1.27	0.98	0.71	3.57	0.57	0.43	0.51	0.84
	RL	4.32	2.00	2.68	3.96	0.68	0.85	1.45	0.62
	BB	1.61	4.64	0.80	4.52	0.50	0.93	0.82	1.01
	WB	2.14	2.91	1.72	4.11	0.48	0.65	0.42	1.10
Lsd _{0.05}		7.9×10^{-4}				0.257			
CV (%)		45				34			

Field 1 (M) is first season of CA treatments, field 2 is maize monocropping for two seasons under CA, field 3 is maize-cowpea-maize rotation and three seasons of CA, field 4 is maize-cowpea-sorghum-maize rotation and four years under CA.

The observed changes in hydraulic conductivity with the introduction of CA practices could be attributed to soil structural improvements that were indicated by changes in bulk density (Table 9c.4 and Fig. 9c.2). Das and Chopra (1988) noted that changes in soil bulk density bring about variations in pore geometry which can significantly influence water movement within the soil matrix. Hydraulic conductivity is a soil property that is dependant on soil water content (Hanks and Ashcroft, 1980). Very high hydraulic

conductivity in field 1 (first season CA treatments) could be attributed to more soil water that was observed in the top 0.10 m under CP system (Table 9c.6). In fact hydraulic conductivity of soil decreases considerably as soil water content changes from saturation to permanent wilting point (Hanks and Ashcroft, 1980). Field 3 (MCM) had lowest capillary sorptivity in planting basins at 0 tha^{-1} mulch. The highest sorptivity in CP and RL was recorded in fields 4 (MCSM) and 3 (MCM). Capillary sorptivity is usually high when the soil is dry at the start of infiltration measurements (Bissett and O'Leary, 1996) as was the case in this study.

9c.4.5 Soil water content before and after infiltration runs

Under the 0 tha^{-1} mulch treatment, field 2 (MM) had highest soil water content observed in RL treatment while field 1 (M) had lowest water content at the same mulch level (Table 9c.6). Under the 4 tha^{-1} mulch cover, the highest soil water content was observed in RL of field 4 (MCSM). The maize-cowpea-maize field (Field 3) under BB tillage treatment had marginally higher initial soil water content under 10 tha^{-1} mulch than the other tillage treatments. One of the major roles played by mulch cover could be reducing soil evaporation. Hatfield *et al.* (2001) observed a 34–50 % reduction in soil water evaporation as a result of crop residue mulching.

Table 9c.6. Volumetric water content (%) measured by capacitance probe in 0 – 0.10 m soil layer before infiltration runs at Matopos Research Station

Mulch (tha ⁻¹)	Tillage	Field number			
		1	2	3	4
0	CP	10	9.8	7.7	8.2
	RL	9.4	18	13	11
	BB	8.5	6.6	9.3	12
4	CP	13	13	11	6.5
	RL	7.3	15	14	16
	BB	9.3	10	15	6.4
10	CP	11	10	6.1	8.2
	RL	11	7.6	11	12
	BB	11	13	14	13

Lsd_{0.05} = 5.8; CV = 26 %

After the infiltration runs field 1 had more ($P = 0.871$) soil water content under 0 tha⁻¹ mulch in CP compared to other fields (Table 9c.7). The same field had slightly more soil water in the CP system than others before the infiltrations runs were made (Table 9c.6) under the 0 tha⁻¹ mulch treatment. The high soil water content after infiltration in CP at 0 tha⁻¹ mulch cover (Table 9c.7) could also be a result of better aligned and linked soil pores created during the ploughing operation resulting in high hydraulic conductivity (Table 9c.5). Vauchin and Chopart (1997) observed increases in hydraulic conductivity and sorptivity in conventionally ploughed treatments and attributed this to better pore connectivity due to turning of the soil. Under the 4 tha⁻¹ mulch soil water content ranged from 10 to 15 % across the five tillage treatments. Under the 10 tha⁻¹ mulch treatment, 22 % soil water content was recorded in basins in field 3 (MCM) while lowest soil water content was 11 % observed in BRL of fields 1 (M) and 2 (MM).

Table 9c.7. Volumetric soil water content (%) in 0 – 0.10 m layer measured after infiltration runs in the four fields at Matopos Research Station

Mulch (tha ⁻¹)	Tillage	Field number			
		1	2	3	4
0	CP	22	12	12	14
	BRL	13	14	14	13
	RL	14	16	12	12
	BB	18	15	11	15
	WB	16	14	15	14
4	CP	15	15	14	15
	BRL	10	13	13	11
	RL	13	14	14	14
	BB	10	14	12	13
	WB	15	15	13	13
10	CP	17	17	15	16
	BRL	11	11	13	15
	RL	12	19	16	12
	BB	15	14	14	14
	WB	16	14	22	16

Lsd_{0.05} = 6.1; CV = 22 %

9c.4.6 Maize crop performance

Table 9c.8 summarizes the main effects of period of exposure to CA practices on maize crop performance at the end of the 2007/08 growing season. The performance of maize crop differed significantly ($P < 0.001$) across the four fields during 2007/08 season. Field 4 (MCSM) produced the highest grain and stover yields and field 1 (M) gave the lowest yields, suggesting improved soil productivity with more years of practicing CA. Field 4 (MCSM) produced 1 970, 1 880 and 679 kg ha⁻¹ more grain than fields 1 (M), 2 (MM) and 3 (MCM). Field 4 (MCSM) also produced 1 905, 1 681 and 946 kg ha⁻¹ more stover than fields 1 (M), 2 (MM) and 3 (MCM). Harvest index was highest in field 3 (MCM) while fields 3 (MCM) and 4 (MCSM) had an average plant stand of 2.6 plants per m². Higher maize yields in field 4 (MCSM) could be attributed to improvements in soil

physical and chemical conditions. Annual application of manure and cowpea stover that was left at the surface after harvest contributed towards soil organic carbon content as well as adding nutrients such as N and P. Cowpea grown as part of a rotation could have fixed N that benefited maize crop in fields 3 (MCM) and 4 (MCSM). Giller *et al.* (1997) reported that in general cowpea grown as sole crop fixes 11 – 210 kgNha⁻¹ in African cropping systems. Changes in soil bulk density improve the soil environment for root growth and exploration for nutrients and water.

Table 9c.8. Maize crop performance measured at the end of the 2007/08 season as influenced by different periods of exposure to CA practices on a clay soil at Matopos Research Station

Field	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index	Plant stand (m ⁻²)
1 (M)	1 028	1 277	0.43	1.7
2 (MM)	1 118	1 501	0.42	1.9
3 (MCM)	2 319	2 236	0.50	2.6
4 (MCSM)	2 998	3 182	0.48	2.6
Lsd _{0.05}	248	210	0.024	0.17
CV (%)	38	29	15	22

The two-way field x tillage system interaction had a significant ($P < 0.001$) influence on grain and stover yields, and plant stand measured across the four fields (Table 9c.9). The lowest grain and stover yields were recorded in the planting basin system in field 1 (M). Field 4 (MCSM) had the highest grain production in all tillage systems. Planting basins in field 4 gave 668 and 665 kg ha⁻¹ more grain than CP and ripper tillage systems. The two-way interaction had no significant ($P = 0.113$) effect on maize harvest index. Planting basins had the highest plant stand in field 3 (2.8 plants per m²) and 4 (3.1 plants per m²) while field 1 (M) had similar plant stand in CP and basin tillage systems (1.6 plants per

m²). During December 2007 and January 2008 fields 1 (M) and 2 (M) were affected by waterlogging in planting basins. Rodent attack at crop establishment and waterlogging during the vegetative stages affected the observed yields in fields 1 (M) and 2 (MM). Plant stand was higher in basins than other two tillage systems in fields 3 and 4 during 2007/08 seasons. The better maize crop establishment under the basin system was reported at on-farm and on-station experiments during the other seasons of experimentation (Chapter 7; Chapter 9a).

Table 9c.9. Maize yield (kg ha⁻¹), harvest index and plant stand (plants m⁻²) responses to three tillage methods at Matopos Research Station in 2007/08 season

Field	Tillage method	Grain Yield kg ha ⁻¹	Stover kg ha ⁻¹	Harvest index	Plant stand #per m ²
1	Plough	1 092	1 312	0.45	1.6
	Ripper	1 222	1 406	0.46	1.9
	Basins	769	1 115	0.40	1.6
2	Plough	1 245	1 610	0.44	1.8
	Ripper	1 097	1 515	0.42	2.0
	Basins	1 013	1 379	0.42	1.9
3	Plough	2 554	2 310	0.51	2.4
	Ripper	1 993	1 977	0.50	2.6
	Basins	2 410	2 422	0.48	2.8
4	Plough	2 774	3 046	0.47	2.2
	Ripper	2 777	2 924	0.49	2.4
	Basins	3 442	3 577	0.49	3.1
Lsd _{0.05}		414	327	0.047	0.70
CV (%)		38	29	15	22

9c.5 Conclusion

The study showed that significant changes in both chemical and physical soil properties occurred during the one to four years the clay soil was exposed to minimum tillage, mulching and crop rotation. Soil organic carbon increased significantly particularly in

planting basins during the four year study period. The maize residue applied as mulch and cowpea stover left in the field after harvesting contributed towards the soil organic carbon pool even between rip lines and planting basins. Minimum tillage resulted in significant positive changes in soil bulk density and hence improved soil physical environment for plant roots. The improved soil conditions increased water infiltration into the soil as indicated by positive changes in soil hydraulic conductivity and capillary sorptivity. Improvements in soil structure due to CA practices give better chances of minimizing rainwater losses from the fields. This potentially increases soil water supply and extends the period of soil water availability to crops in smallholder cropping systems.

Improvements in soil physical and chemical environment were also reflected in maize yield differences observed in fields exposed for different periods to CA practices. The field with four years of exposure to CA practices outperformed the other three fields in all maize parameters measured. Improvements in soil fertility due to annual application of manure and crop residues left on the surface resulted in higher maize yields with a longer period of practicing CA. The improved soil physical environment, as shown by positive changes in bulk density, enables plant roots to explore more soil volume for water and nutrients resulting in improved productivity in semi-arid smallholder cropping systems.

CHAPTER 10

Productivity of Planting Basin Tillage System and Nitrogen under Highly Variable Rainfall Regimes of Semi-Arid Southern Zimbabwe: A Modelling Assessment

10.1 Introduction

In semi-arid regions high spatial and temporal rainfall variability presents a big challenge to rainfed smallholder agriculture. Reduced crop yields and total crop failures are a common feature in semi-arid farming systems. In growing seasons with above average rainfall crop yields still remain low due to soil fertility constraints. In wet seasons smallholder farmers fail to make effective use of available soil water and cereal yields from unfertilized granitic sands remain below 500 kg ha⁻¹ (Shamudzarira and Robertson, 2002; Chapter 7).

The advent of conservation farming using planting basins brought a ray of hope to smallholder farmers in semi-arid districts of Zimbabwe. The planting basin tillage system enables farmers to prepare land early spread the limited farm labour and plant on time with respect to the effective planting rain. The planting basins created in a grid of 0.9 m x 0.6 m spacing harvest rainwater and reduce surface runoff from cropping fields (Mupangwa *et al.*, 2008). Substantial crop yields obtained from the planting basin system have been reported in several semi-arid districts of Zimbabwe (Nyagumbo, 2007; Twomlow *et al.*, 2008a) and on agricultural research stations (Chapter 9a).

Although planting basins on smallholder farms have been in use for only four growing seasons, the use of simulation modeling can help understand the long-term impact of the tillage system under semi-arid conditions. The Agricultural Production Simulator Model (APSIM) is a deterministic, process based model that has been used for simulating crop production in smallholder cropping systems. The APSIM model has performed well in predicting crop production and its interaction with climate, soil and management factors (Keating *et al.*, 2003). In smallholder farming systems, APSIM has been used with success to simulate nitrogen (N) dynamics of manure inputs (Delve and Probert, 2004), maize response to N (Shamudzarira and Robertson, 2002), water use efficiency (Dimes and Malherbe, 2006), and N and water stress dynamics in cereal-legume rotations (Ncube *et al.*, 2008). However, no description of the effect of mulch on crop yields and soil water dynamics under conventional, ripper and planting basin tillage systems is included in any of the previous studies.

10.2 Objectives

The main objectives of the current study were to evaluate the capability of APSIM (version 6.0) cropping systems model to simulate maize yield and soil water responses to different seasons, mulch levels and three tillage systems on two soil types. Data obtained from on-station experiments (Chapter 9a) will be used to verify model performance. Then to use the validated APSIM model to assess the long term interaction effects of N and two tillage systems, conventional and planting basins, on maize yields and selected components of the soil water balance for a granitic sand soil in semi-arid areas of southern Zimbabwe. The specific objectives were:

- (1) to evaluate APSIM capability in predicting the seasonal and mulching effects on maize grain and total biomass yields;
- (2) to evaluate APSIM capability in predicting effects of conventional, ripper and planting basin tillage techniques on soil water regimes; and
- (3) to use the validated APSIM model to assess the long term interaction effects of N fertilizer, and conventional and planting basin tillage systems on maize yields, surface runoff and deep drainage.

10.3 Materials and Methods

10.3.1 Set up of the model

10.3.1.1 Climate parameters

Daily rainfall, temperature and radiation data were collected from Matopos Research Station weather station which is located 3 km from Matopos experimental site and up to 10 km from the Lucydale site. The climate record used for APSIM calibration stretched from 1 October 2004 to 30 June 2008. The simulation was run from 1 October 2004 to 30 June 2008 and the model was reset every 1 July to initial soil organic carbon, nitrogen and water content.

10.3.1.2 Soil water and soil characteristics

Soil parameters used for calibrating the APSIM model are given in Tables 10.1 and 10.2. As the experiment for Chapter 9a had a new field established in each season, the PAWC for 2004/05 field 4 was 116 mm, 2005/06 was 84 mm for field 3, for 2006/07 was 61 mm for field 2 and for 2007/08 was 84 mm for field 1 in the 0 – 0.85 m soil profile. The

drained upper limit (DUL), saturation (SAT) and lower limit (LL) were derived from soil water measurements made in the basins with zero mulch. For Lucydale PAWC in the 0 – 0.70 m soil profile was 84 mm for 2004/05 and 2005/06 seasons. The Lucydale soil water parameters were adopted from Masikati (2006). The field used by Masikati (2006) was adjacent to our experimental field for both 2004/05 and 2005/06 seasons.

Soil nitrate-N for Matopos clay soil was assumed total N was 25 kg ha⁻¹ (20 kg NO₃⁻ and 5 kg NH₄⁺). Soil water and organic matter were reset to zero on the first of July each year while N was reset to 25 kg ha⁻¹ on the same date. It was assumed that the 3 t ha⁻¹ of manure used in our experiment supplied 9.6 kg N ha⁻¹. Runoff curve number for bare soil was set at 85. For the plough and ripper tillage systems the curve number was adjusted downwards by 10 units which were lost after 50 mm of rainfall, so it then reverted to 85. For the basins the curve number was adjusted downwards by 20 units which were lost after 250 mm of rainfall was received. The C:N ratio of mulching material was set at 60 (0.67 % N) and a 10 % incorporation of the mulching material in the CP system was assumed. For basins and ripper tillage a 0 % incorporation of the mulching material was assumed.

Table 10.1. Soil chemical and physical properties of the clay soil used for Matopos Research Station experimental site (from ICRISAT unpublished data)

Depth (cm)	pH	NO ₃ -N (ppm)	Organic carbon (%)	Bulk density (gcm ⁻³)	DUL (mm/mm)	LL (mm/mm)
0-15	6.0	6.50	1.2	1.4	0.20	0.10
15-25	6.0	2.10	1.0	1.4	0.24	0.10
25-35	6.0	2.10	0.86	1.4	0.26	0.13
35-45	6.0	1.70	0.83	1.4	0.27	0.16
45-55	6.0	1.70	0.58	1.4	0.29	0.20
55-65	6.0	1.70	0.54	1.4	0.29	0.21
65-75	6.0	1.70	0.54	1.4	0.30	0.23
75-85	6.0	1.70	0.5	1.4	0.31	0.25

Table 10.2. Soil chemical and physical properties of the sand soil used for Lucydale experimental site (from Masikati, 2006)

Depth (cm)	pH	NO ₃ -N (ppm)	Organic carbon (%)	Bulk density (g/cm ³)	DUL (mm/mm)	LL (mm/mm)
0-20	6.3	4.3	0.8	1.66	0.15	0.05
20-30	6.3	3.2	0.7	1.65	0.22	0.13
30-40	6.9	1.5	0.7	1.60	0.28	0.20
40-50	6.9	1.5	0.7	1.55	0.34	0.27
50-60	6.9	1.5	0.7	1.51	0.37	0.32
60-70	6.3	1.1	0.6	1.34	0.41	0.36

10.3.1.3 Crop parameters

APSIM crop module contains a description of the short season hybrid variety SC401 used in Zimbabwe. In our experiment a short seasoned hybrid variety SC403 was planted at Matopos in all seasons and at Lucydale in 2005/06. An open pollinated variety ZM421 was planted at Lucydale in 2004/05 season because there was a maize breeding experiment close to our research field. The three varieties are drought tolerant and recommended for semi-arid areas of Zimbabwe. Hence APSIM crop parameters for SC401 were selected to describe both SC403 and ZM421 used in the study.

10.3.1.4 Experimental management

Experimental management in the model was according to the experimental procedures (Chapter 9a). Sowing, manure application and topdressing dates for Matopos and Lucydale experimental sites are given in Tables 10.3 and 10.4. For plough treatments at Lucydale manure was applied a day before sowing in each season, sowing being 14 and 13 December for 2004/05 and 2005/06 seasons according to the rain received. For planting basins treatment at Lucydale manure was applied on 26 October 2004 and 14 September 2005 for 2004/05 and 2005/06 growing seasons. A sowing depth of 50 mm was used in the simulation for each tillage system. Average plant stands of 1.8 and 3.1 plants per m² were used for Lucydale in 2004/05 and 2005/06 seasons. For Matopos 3.0 plants per m² was used for all seasons. All plots were kept weed free during period of experimentation. The APSIM model simulated maize yield and soil water balance until the crop was mature.

Table 10.3. Dates for field activities carried out at Matopos Research Station during the four seasons of experimentation (Chapter 9a)

Season	Tillage method	Mulch application	Manure application	Sowing date	Topdressing date
2004/05	Plough	10/11/2004	12/12/2004	13/12/2004	21/1/2005
	Ripper	10/11/2004	26/10/2004	13/12/2004	21/1/2005
	Basins	10/11/2004	20/10/2004	13/12/2005	21/1/2005
2005/06	Plough	15/9/2005	13/12/2005	13/12/2005	24/1/2006
	Ripper	15/9/2005	18/9/2005	13/12/2005	24/1/2006
	Basins	15/9/2005	17/9/2005	13/12/2005	24/1/2006
2006/07	Plough	28/7/2006	7/12/2006	8/12/2006	2/1/2007
	Ripper	28/7/2006	30/8/2006	21/11/2006	2/1/2007
	Basins	28/7/2006	28/8/2006	21/11/2006	2/1/2007
2007/08	Plough	25/7/2007	12/12/2007	12/12/2007	10/1/2008
	Ripper	25/7/2007	5/8/2007	12/12/2007	10/1/2008
	Basins	25/7/2007	27/9/2007	12/12/2008	10/1/2008

Table 10.4. Dates for field activities carried out at Lucydale experimental site during the two seasons of experimentation (Chapter 9a)

Season	Tillage method	Mulch application	Manure application	Sowing	Topdressing
2004/05	Plough	17/10/2004	13/12/2004	14/12/2004	21/1/2005
	Ripper	17/10/2004	25/10/2004	14/12/2004	21/1/2005
	Basins	17/10/2004	26/10/2004	14/12/2004	21/1/2005
2005/06	Plough	*	12/12/2005	13/12/2005	24/1/2006
	Ripper	*	8/9/2005	13/12/2005	24/1/2006
	Basins	*	14/9/2005	13/12/2005	24/1/2006

* No fresh mulch was applied

10.3.2 Long term simulation

The long term simulation was run using soil properties of the Lucydale granitic sandy soil (Table 10.2). The 69 year climate record (1939 – 2008) derived from Matopos Research Station weather station was used in the long term simulation. The following scenarios were used in long term simulation:

- Conventional ploughing plus four N rates (0, 10, 20 and 52 kg ha^{-1})
- Planting basins plus four N rates (0, 10, 20 and 52 kg ha^{-1})

The N rates of 0, 10 and 20 kg ha^{-1} were similar to N levels used in the on-farm experiments conducted in Gwanda and Insiza districts of southern Zimbabwe between 2005/06 and 2007/08 seasons. The 52 kg Nha^{-1} is the national recommendation for smallholder cropping systems of Zimbabwe (Twomlow *et al.*, 2008a) so it was included to provide a comparison with what may be considered as providing optimal yields.

10.3.3 Reporting frequency

For the on-station experiments the model was set to report selected variables on a daily time step. The reported variables for the on-station experiments were total biomass and grain yield, and profile water content in the 0 – 0.25 m layer. In the long term simulation the model was set up to report variables at harvest stage of the maize crop. Total biomass and grain yields were reported at 0 % moisture content and are compared to observed yields at this moisture content. In the long term simulation the reported variables were grain yield, pre-sowing and in-crop surface runoff, and in-crop deep drainage.

Genstat Discovery Edition 3 (www.vsnl.co.uk) was used to analyze maize yield and soil water data. The root mean square deviation (RMSD) values were calculated for comparison of observed and predicted data. The RMSD was calculated as follows:

$$RMSD = [1/n \sum (x_i - y_i)^2]^{0.5} \quad \text{Equation 10.1}$$

where x_i is the observed yield or soil water content, y_i is the predicted yield or soil water content and n is the number of observations.

Modeling Efficiency (ME) was calculated as follows:

$$ME = \frac{\left[\sum_{i=1}^n (o_i - \bar{o})^2 - \sum_{i=1}^n (p_i - o_i)^2 \right]}{\sum_{i=1}^n (o_i - \bar{o})^2} \quad \text{Equation 10.2}$$

where P_i and O are predicted and observed values respectively, $\bar{O}$ is observed mean value (Rinaldi *et al.*, 2003).

10.4 Results and Discussion

10.4.1 Maize yields

The total growing seasonal rainfall for 2004/05, 2005/06, 2006/07 and 2007/08 was 320, 915, 467 and 364 mm respectively. The predicted seasonal and mulching effects on grain and biomass yields at Matopos are shown in Figures 10.1 and 10.2. APSIM was able to predict closely the seasonal effects on grain ($ME = 0.86$) and biomass ($ME = 0.84$) yields for the four seasons with different rainfall pattern at Matopos. The model gave a good prediction of grain yield in 2004/05 which was an average season in terms of rainfall received. For the below average rainfall seasons 2006/07 and 2007/08, APSIM predicted low maize grain and biomass production on the Matopos clay soil which did not really match the observed values. The model poorly predicted grain ($ME = 0.27$) and biomass ($ME = 0.49$) production at Lucydale for 2004/05 and 2005/06 seasons under the set model input conditions (Fig. 10.3).

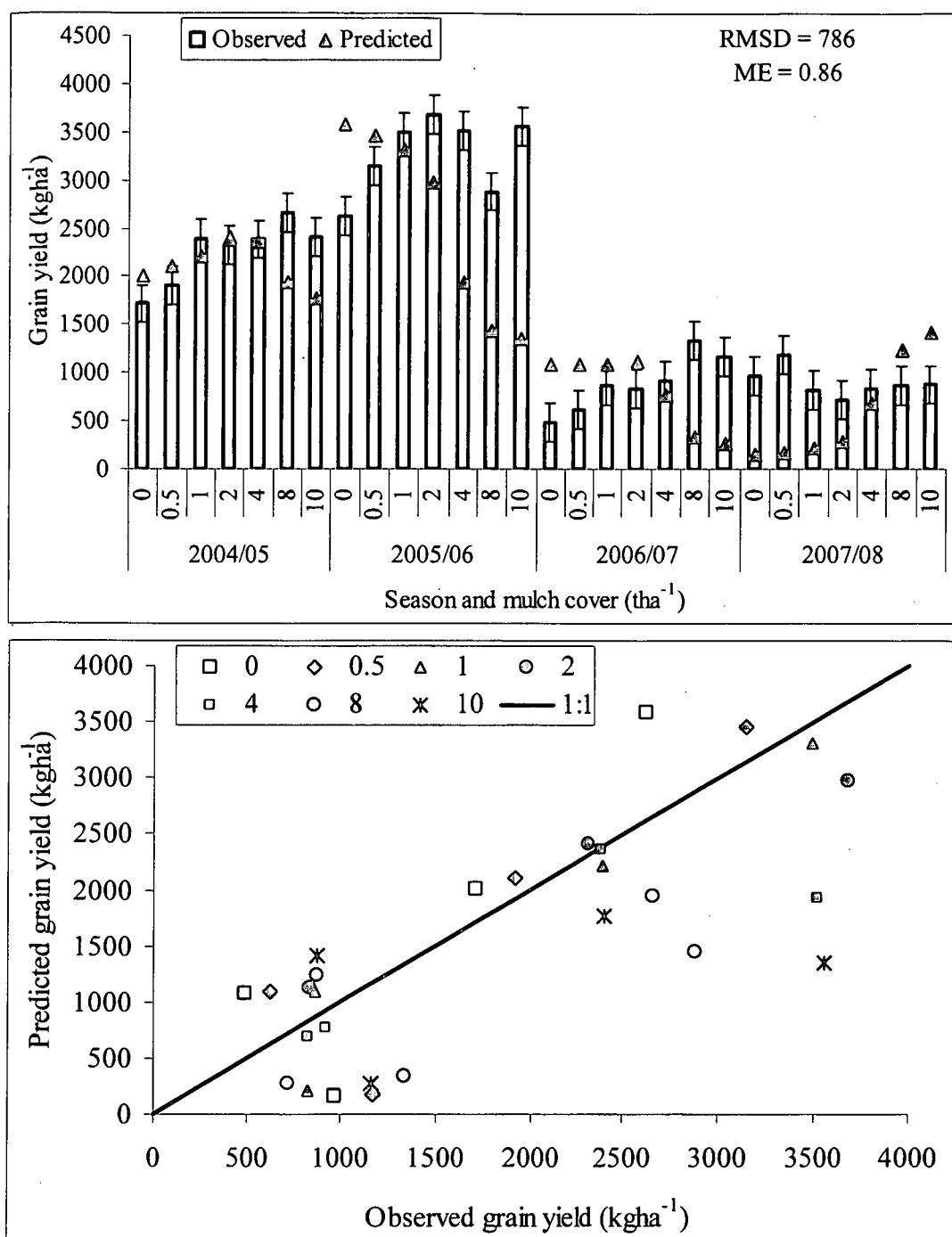


Figure 10.1. Observed and predicted grain yield from different mulch levels over four growing seasons at Matopos Research Station. Error bars stand for standard error of means for the different mulch levels in each season. $R^2 = 0.67$ (averaged across seven mulches)

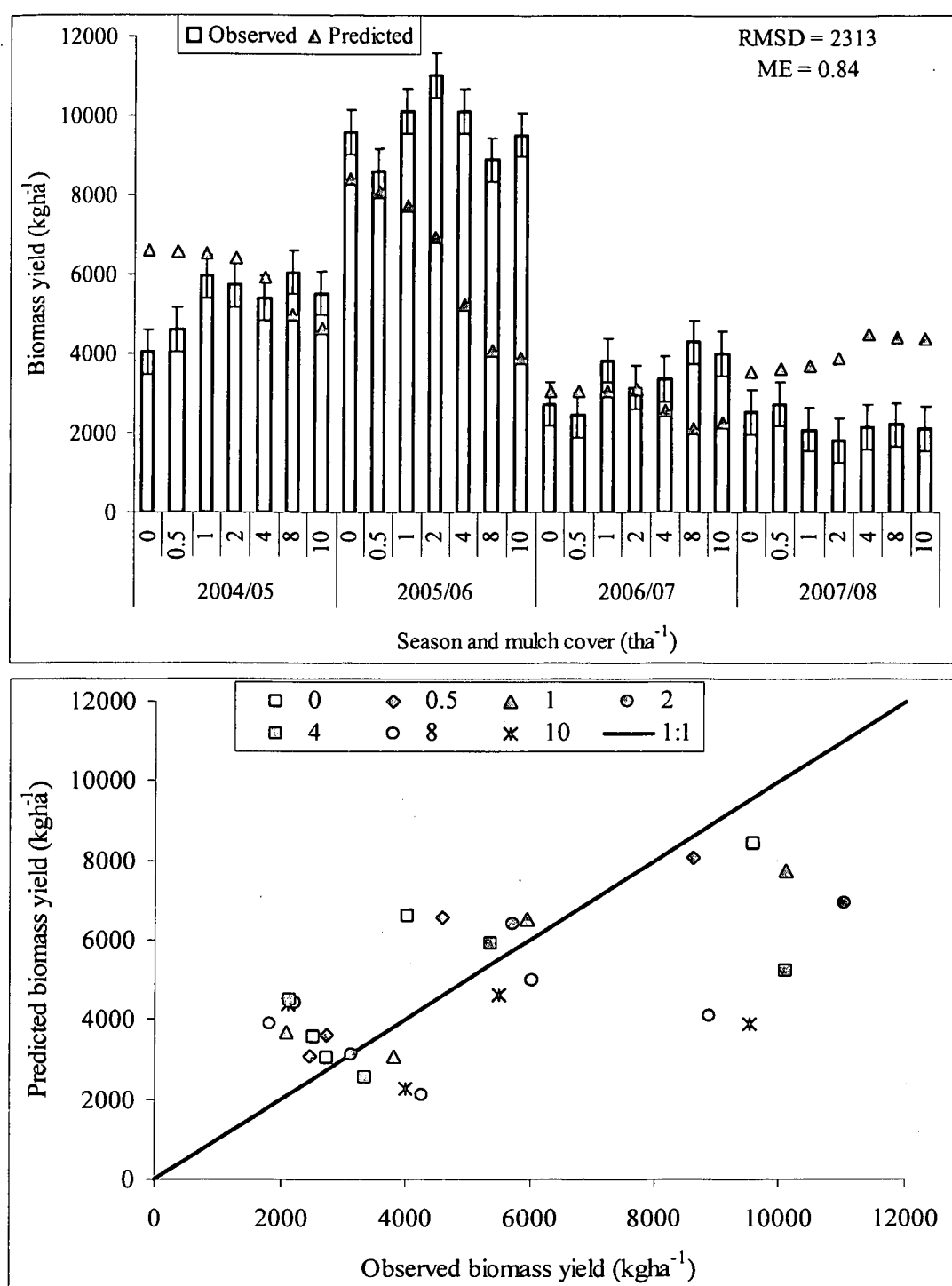


Figure 10.2. Observed and predicted total biomass yields from different mulch levels over four growing seasons at Matopos Research Station. Error bars stand for standard error of means for the different mulch levels in each season. $R^2 = 0.50$ (averaged across seven mulch levels)

The mulching effect on grain and biomass yields in the four different seasons at Matopos is shown in Figure 10.1. For 2004/05, 2005/06 and 2006/07 seasons the model over predicted grain yield at 0 and 0.5 tha^{-1} mulch cover. The model under predicted grain production at 8 and 10 tha^{-1} mulch cover in the same seasons. In 2007/08 the model under predicted grain production at low mulch levels ($< 4 \text{ tha}^{-1}$) while over predicting it at 8 and 10 tha^{-1} (Fig. 10.1). For the wetter 2005/06 season the model under predicted biomass production and indicated a decrease in yield with increase in mulch cover on the clay soil (Fig. 10.1). This is in contrast to what happened in the field experiment at Matopos (Chapter 9a). The mulch cover could have promoted a proliferation of soil micro-organisms given the better supply of soil water during 2005/06 season. To be able to decompose the maize residue mulch soil micro-organisms need energy and therefore out-competed the maize plants in extracting soil N. The 29.6 kgNha^{-1} was probably not enough to meet microbial and crop requirements thereby resulting in inadequate N supply to the maize crop and thus a lower predicted yield at higher mulch levels. Yellowing of maize foliage indicating N deficiency was quite evident at 8 and 10 tha^{-1} mulch level particularly at the Matopos experimental site resulting in lower yield being achieved at 8 tha^{-1} mulch (Fig. 10.1). Degradation of the mulching material could have been driven by termites which, unlike soil micro-organisms, do not need to take up N from the soil in order to degrade the plant residues (Konig and Varma, 2006).

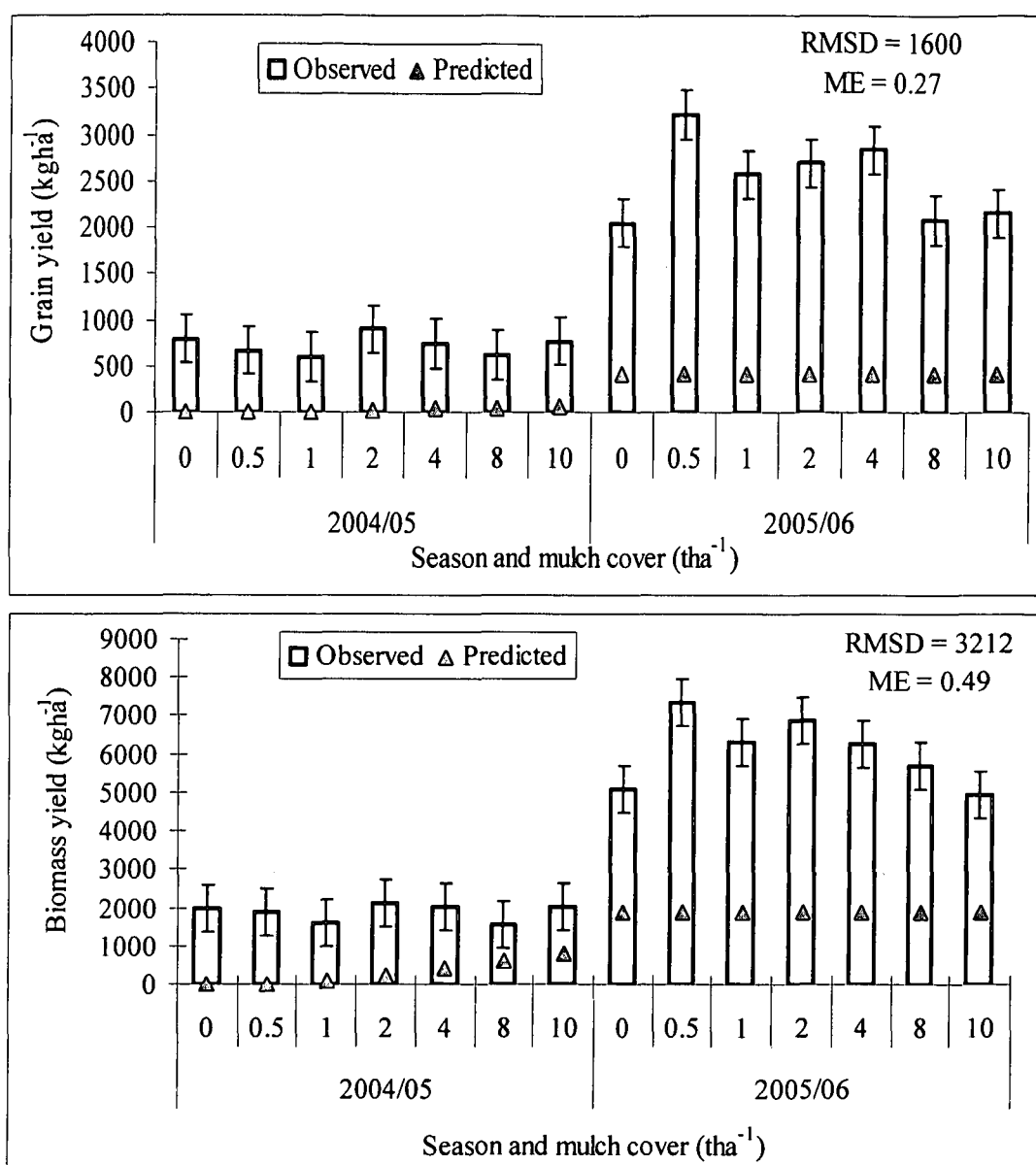


Figure 10.3. Observed and predicted grain and total biomass yields for different mulch levels on a sand soil over two growing seasons at Lucydale experimental site. Error bars stand for standard error of means across three replications

The model under predicted maize biomass production with more mulch cover during the 2005/06 growing season at Matopos (Fig. 10.2). In the 2007/08 season the model predicted an increase in biomass yield with higher mulch cover at Matopos (Fig. 10.2). The model is probably indicating soil water benefits derived from mulching in 2007/08

season that was characterized by an abrupt end of rain in January 2008. The higher mulch cover conserved and supplied soil water to take the maize crop to maturity. However, observed maize yield data did not show any significant influence of mulch cover on total biomass or grain yields. This is rather puzzling given the early cessation of rainfall at a time when maize crop was at its reproductive stage. The over prediction of grain yield in 2004/05, 2005/06 and 2006/07 seasons at low mulch levels could be an indication of better N supply because there was no immobilization of applied nitrogen.

At Lucydale sandy soil site, the model under predicted no grain yield responses to freshly applied mulch cover in 2004/05 and residual mulch cover in 2005/06 seasons (Fig. 10.3). Lack of grain yield responses to freshly applied and residual mulch in 2004/05 and 2005/06 is consistent with observed results. Field observations made in all seasons showed that maize residue applied as mulch decomposed quite fast particularly in a season with a lot of rain like 2005/06. At the end of growing season (April/May) there was hardly any maize residue left in the experimental plots especially where 0.5, 1 and 2 tha^{-1} had been applied. An estimated 30 - 40 % mulch cover would be remaining in the 8 and 10 tha^{-1} treatments. Maize residue, with a C:N ratio averaging 52 (Nhamo, 2007), decomposes fast when conditions of drivers of decomposition such as rainfall, temperature and soil micro-organisms are ideal (Heal *et al.*, 1997).

10.4.2 Soil water regimes

Soil water predictions from APSIM were compared with observed data at Matopos site for the 2006/07 and 2007/08 growing seasons. In the both seasons, the model over

predicted soil water content of the top (0 – 0.25 m) soil layer under the conventional, ripper and basin tillage systems (Figs. 10.4 and 10.5). The soil water patterns were quite similar in plough, ripper and basin tillage systems. The relationship between observed and predicted soil water data (Figs. 10.4 and 10.5) indicates that APSIM was not always able to closely predict soil water content in the plough, ripper and basin systems under the conditions that we set up the model the prediction for 2006/07 season was better than 2007/08.

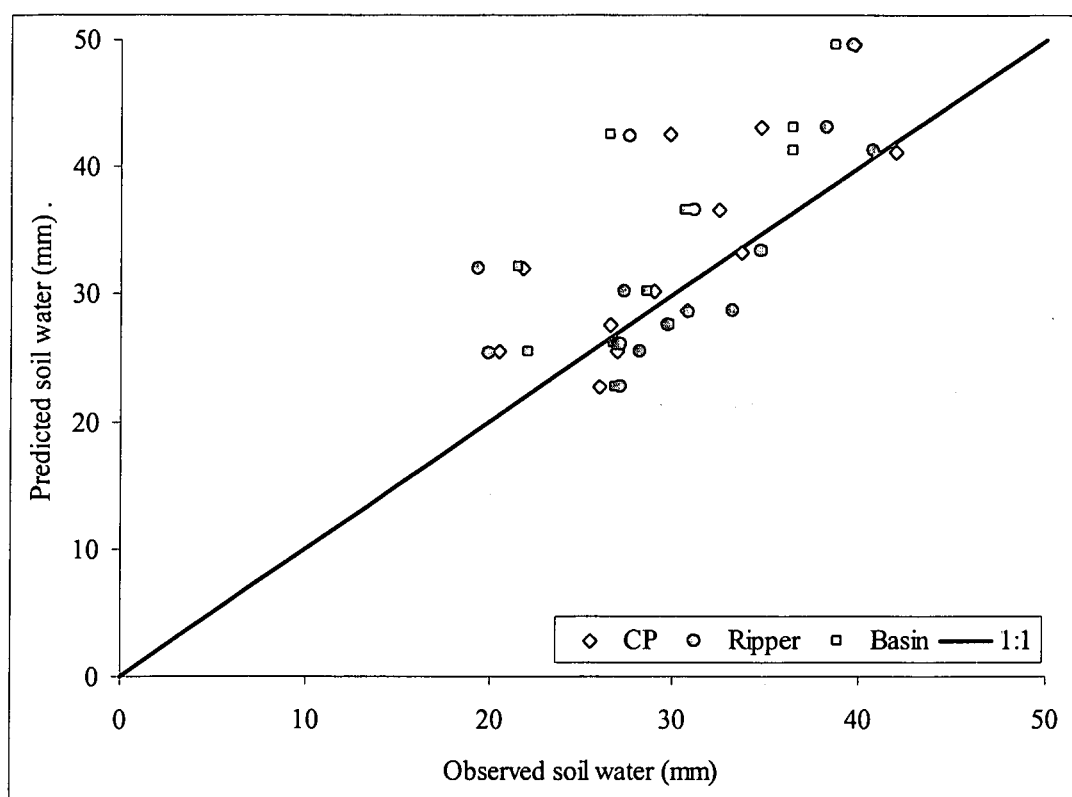


Figure 10.4. Observed and predicted soil water content in a clay soil (0 – 0.25 m layer) under plough, ripper and basin tillage systems at Matopos Research Station during 2006/07 growing season

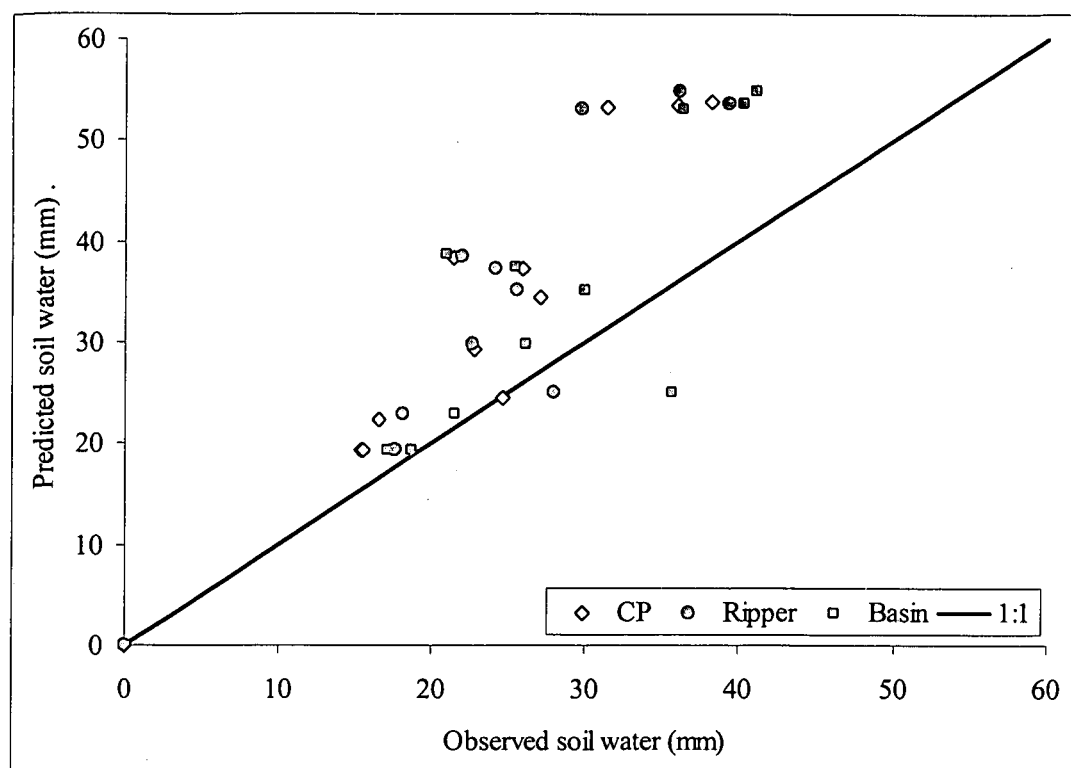


Figure 10.5. Observed and predicted soil water in a clay soil (0 – 0.25 m layer) under plough, ripper and basin tillage systems at Matopos Research Station during 2007/08 growing season

In all tillage systems, the model predicted closely the long term drying after 29 February 2008 (day 152) until the last soil water measurement was taken (Fig. 10.6). The similarities in predicted soil water regimes under plough, ripper and basin tillage systems are consistent with results from on-station and on-farm experimentation (Chapters 7, 9a and 9b; Mupangwa *et al.*, 2008). Earlier studies at Lucydale experimental site showed that the model can also predict soil water regimes in legume-cereal rotations (Ncube *et al.*, 2008).

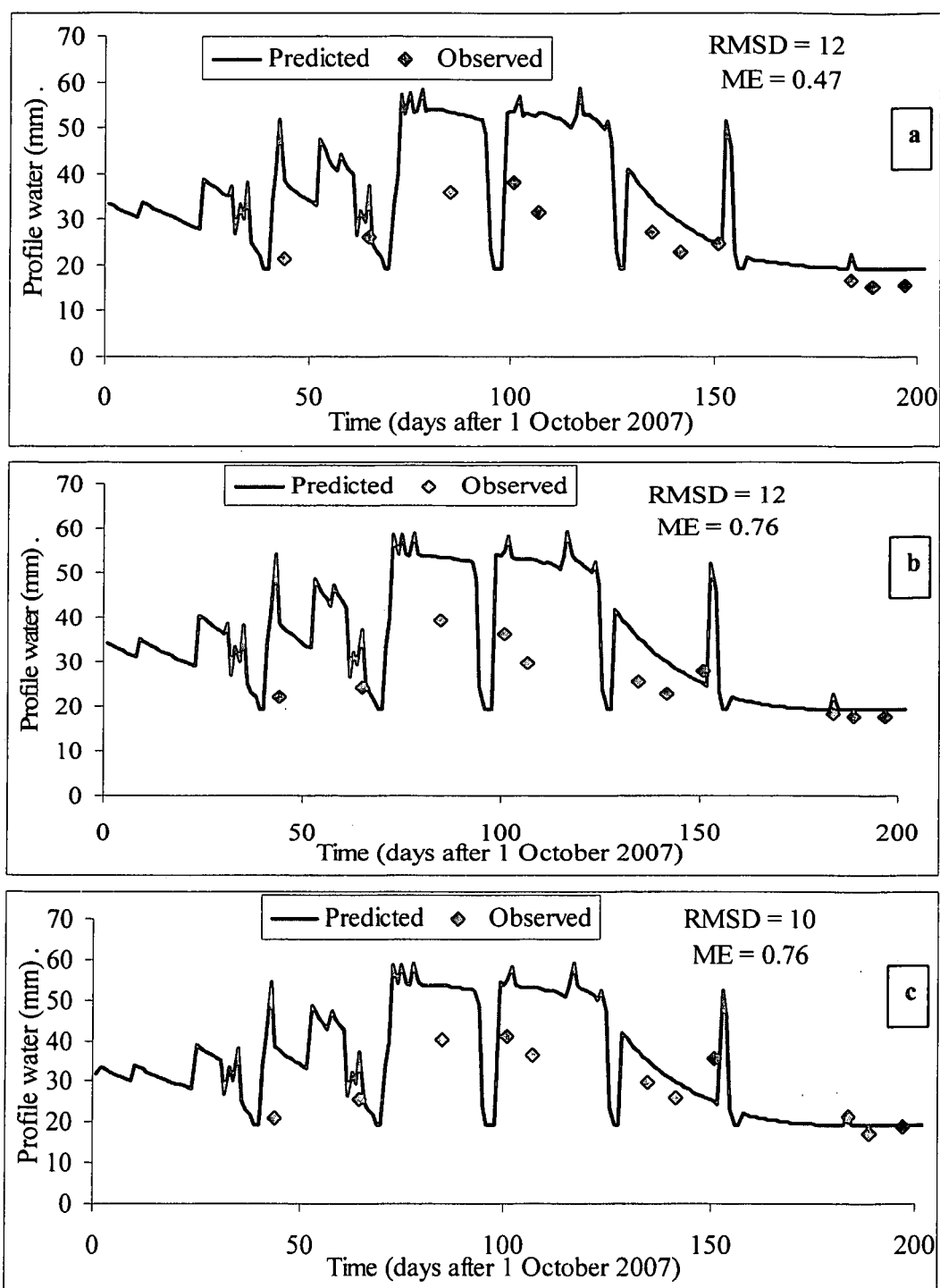


Figure 10.6. Observed and predicted soil water in a clay soil (0 – 0.25 m layer) under plough (a), ripper (b) and basin (c) tillage systems at Matopos Research Station during 2007/08 growing season

10.4.3 Long term impact of conventional and planting basin tillage systems

10.4.3.1 Grain yield

The relationship between maize grain yields from conventional ploughing and planting basin tillage systems is shown in Figure 10.7. The model predicted marginally higher ($P = 0.11$) grain yield in the basin system than the conventional system at each nitrogen level used (Fig. 10.7). The model predicted mean grain yield of 945 kg ha^{-1} without N application, $1\,112 \text{ kg ha}^{-1}$ at 10 kg N ha^{-1} and $1\,216 \text{ kg ha}^{-1}$ at 20 kg N ha^{-1} under the conventional ploughing system. At the recommended 52 kg N ha^{-1} application, the model predicted a mean yield of $1\,296 \text{ kg ha}^{-1}$ over the 69 year period under the conventional ploughing system. Under the basin tillage system, the model predicted mean grain yield of $1\,025 \text{ kg ha}^{-1}$ without nitrogen, $1\,175 \text{ kg ha}^{-1}$ with 10 kg N ha^{-1} and $1\,280 \text{ kg ha}^{-1}$ at 20 kg N ha^{-1} . At the standard recommended 52 kg N ha^{-1} , the model predicted a mean grain yield of $1\,364 \text{ kg ha}^{-1}$ over the 69 year period. The additional maize yield benefits from increasing N application rate could not have been realized because soil water was limiting under semi-arid conditions in both the conventional ploughing and basin systems. Other studies have shown that in drought-prone environments of Zimbabwe crop response to fertilizer is highly dependent on seasonal rainfall distribution (Shumba *et al.*, 1992; Nyakatawa *et al.*, 1996).

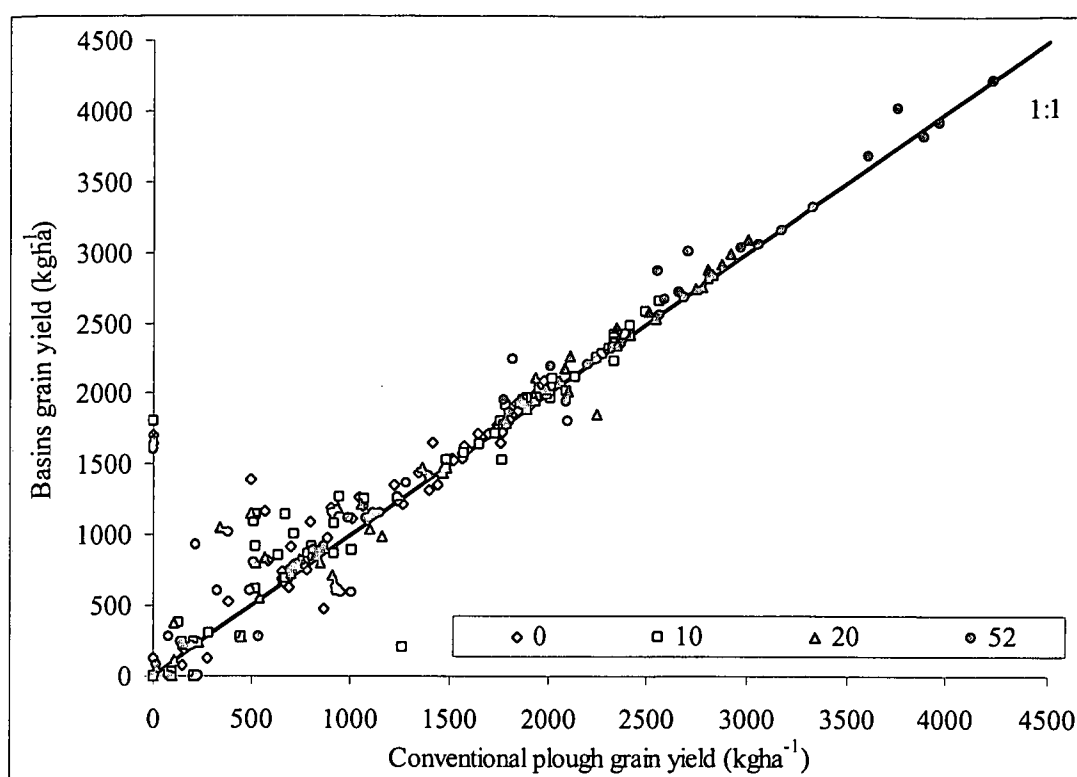


Figure 10.7. Comparison of grain yield achieved in the conventional and basin tillage systems at four N application rates (0, 10, 20 and 52 kgNha⁻¹) on a granitic sandy soil under semi-arid conditions

The model predicted near-normal grain yield of 563 to 1 435 kg ha⁻¹ without N, 508 to 1 761 kg ha⁻¹ at 10 kgNha⁻¹ and 448 to 1 930 kg ha⁻¹ with 20 kgNha⁻¹ under the conventional ploughing system. At the recommended 52 kgNha⁻¹, the model predicted near-normal grain yield of 337 to 1 796 kg ha⁻¹ under the conventional ploughing system. Under the basin system, the model predicted near-normal grain yield of 665 to 1 536 kg ha⁻¹ at 0 kgNha⁻¹, 604 to 1 801 kg ha⁻¹ with 10 kgNha⁻¹ and 630 to 1 895 kg ha⁻¹ at 20 kgNha⁻¹. The predicted near-normal grain yield was 592 to 1 862 kg ha⁻¹ at recommended 52 kgNha⁻¹ under the basin system. It is notable that there is little difference in modeled yield across the N levels at yield values less than 1 500 kg ha⁻¹ which occurs 60 % of the time. The 33-66 % maize yield ranges are narrower in the basin system at 10, 20 and 52 kgNha⁻¹

compared to the conventional system. This implies that it is less risky to use these nitrogen fertilizer levels in the basin tillage system than the conventional system.

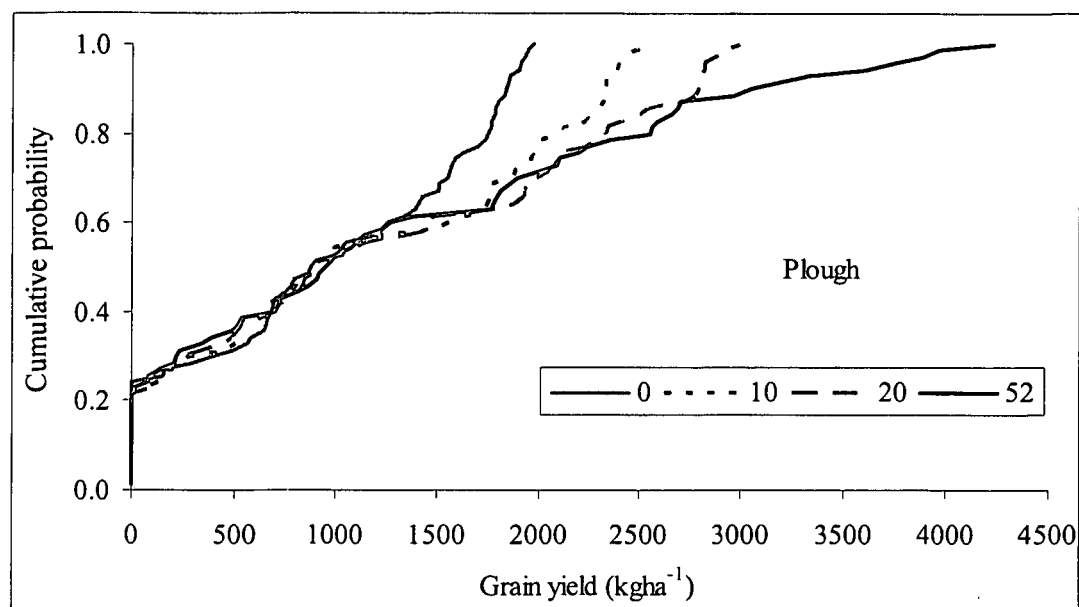


Figure 10.8. Cumulative distribution function for maize grain yield response to four N application rates (0, 10, 20 and 52 kgNha⁻¹) on a granitic sandy soil in the conventional tillage system under semi-arid conditions

In 15 out of the 69 years the model predicted no grain yield at any of the N rates in the conventional tillage system (Fig. 10.8). In the planting basin system 14 years would not produce any grain regardless of the N treatment. This is consistent with observations from on-farm experimentation in Gwanda and Insiza districts during 2006/07 and 2007/08 growing seasons when no maize yields were obtained on most smallholder farms (Chapter 6; Chapter 7). Considering the extreme maize yields predicted by the model, the highest predicted grain yield are 1 981 kg ha⁻¹ without N fertilizer, 2 562 kg ha⁻¹ with 10 kgNha⁻¹ and 2 998 kg ha⁻¹ at 20 kgNha⁻¹ for the conventional tillage system (Fig. 10.8). The highest predicted grain yield at 52 kgNha⁻¹ is 4 228 kg ha⁻¹ in the conventional

ploughing system. Under the basin system, the highest predicted grain yield was 2 090 kg ha^{-1} with no nitrogen fertilizer, 2 661 kg ha^{-1} at 10 kg N ha^{-1} and 3 098 kg ha^{-1} with 20 kg N ha^{-1} . At the recommended 52 kg N ha^{-1} , the highest predicted grain yield is 4 223 kg ha^{-1} in the basin system (Fig. 10.9).

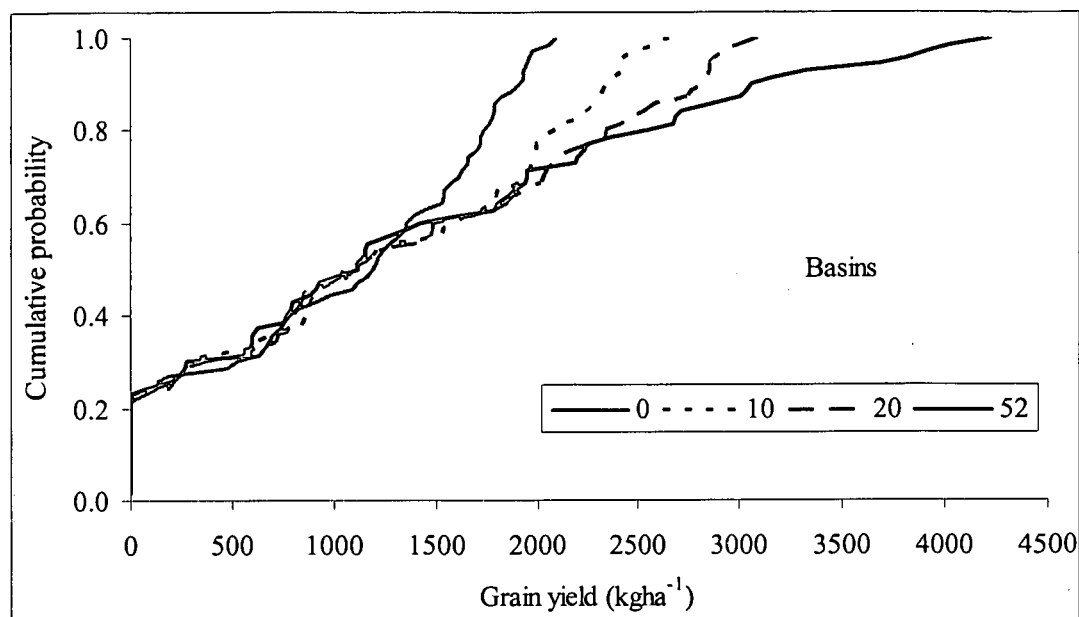


Figure 10.9. Cumulative distribution function for maize grain yield response to four N application rates (0, 10, 20 and 52 kg N ha^{-1}) on a granitic sandy soil in the basin tillage system under semi-arid conditions

10.4.3.2 Surface runoff and deep drainage

The predicted surface runoff water losses before the start of and during the crop growing season are given in Figure 10.10. During the pre-cropping period the model predicted higher ($P < 0.05$) runoff water losses from the conventional system compared to the basin system. The 0.9 m x 0.6 m grid of basins creates surface depressions which help capturing rainwater. However, during the cropping period runoff water losses are similar in most years suggesting that the planting basins would have lost the ability to retain

rainwater. The effect of planting basin on surface runoff dissipates as the growing season progresses. The planting basin structure in sandy soils was observed to collapse fast depending on the frequency and intensities of rainstorms received (Chapter 7; Mupangwa *et al.*, 2008). Only four out of the 69 years had more predicted in-crop runoff water losses from planting basins than conventional system. The predicted pre-crop runoff ranged from 0.3 to 103 mm per year for the conventional tillage system with a mean value of 21 mm. Pre-crop predicted runoff ranged from 0.1 to 88 mm for basin tillage system with a mean value of 15 mm. APSIM predicted more deep drainage water losses from the basin tillage system compared to the conventional system during the cropping period (Fig. 10.11). The simulated deep drainage water losses ranged from 0 to 109 mm with a mean of 19 mm in the conventional system. The basin system had 0 to 160 mm with a mean of 22 mm.

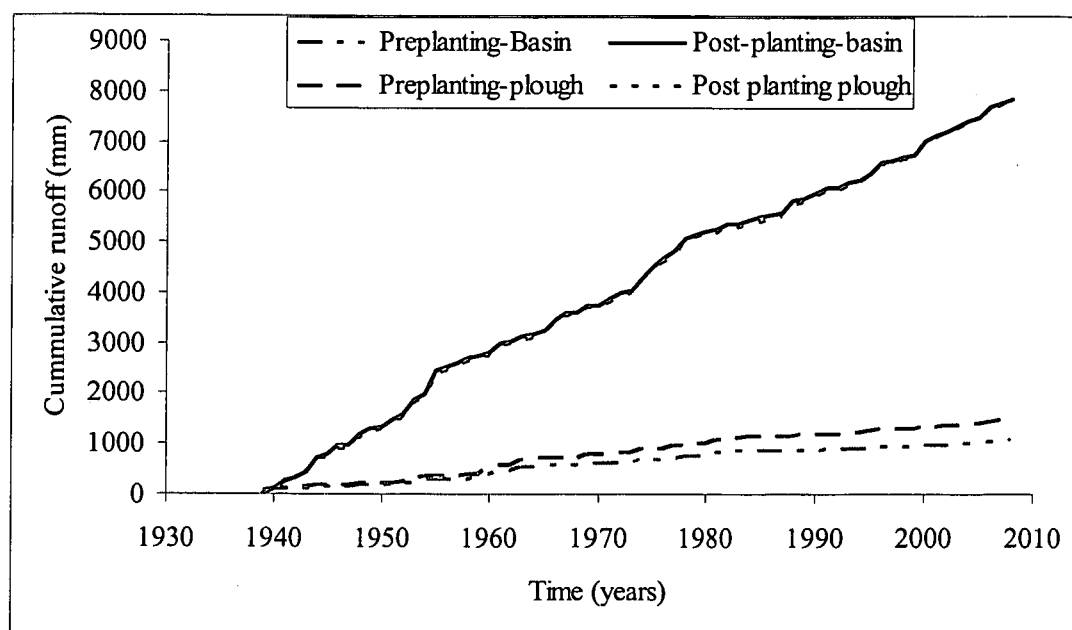


Figure 10.10. Surface runoff water losses from the conventional ploughing and basin tillage systems on a granitic sandy soil under semi-arid conditions

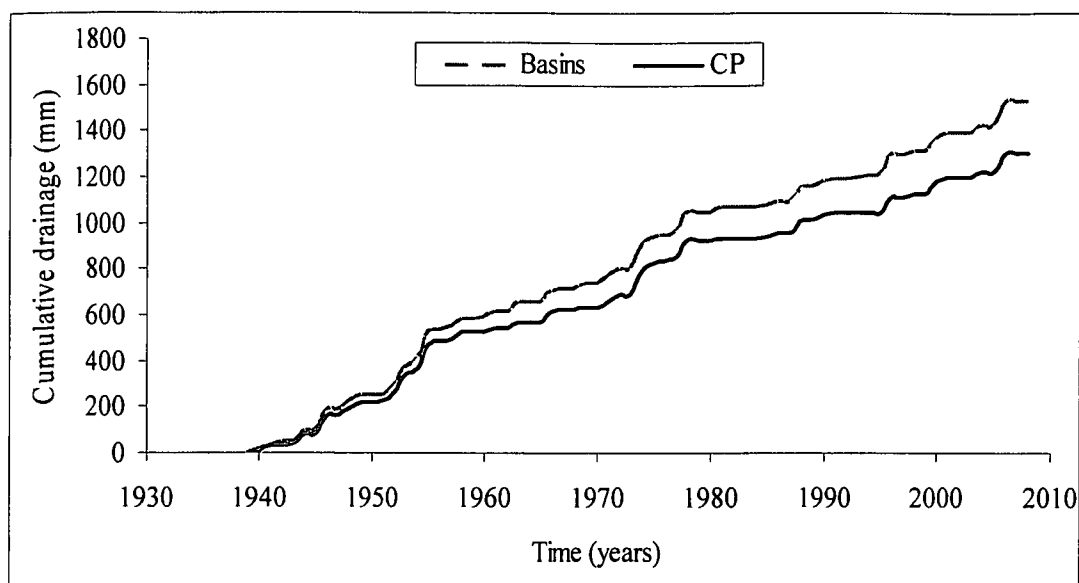


Figure 10.11. Deep drainage soil water losses from conventional ploughing and basin tillage systems during the crop growing period under semi-arid conditions

10.5 Conclusion

The APSIM model was used in this study to predict the observed crop yield and profile soil water and give a long term impact of the planting basin system on maize yield and selected components of the water balance. For most of the seasons there was reasonable agreement between observed and predicted maize yield data sets for the Matopos experimental site (clay soil). However, for the sandy soil Lucydale site, APSIM under predicted grain and biomass production under the model input conditions set suggesting that the model still requires more calibration for the CA systems or rainwater harvesting techniques such as planting basins and ripper that were tested together with mulching. The model over predicted soil water in the conventional ploughing, ripper and basin tillage systems regardless of the mulch level applied.

Long term simulations showed that maize productivity under semi-arid conditions can be improved significantly through application of N fertilization in both conventional and

planting basins tillage systems. The predicted maize yield indicated that 0, 10, 20 and 52 kgNha⁻¹ give no yield difference below 1 500 kgha⁻¹. The response to N fertilizer varies from season to season depending on the rainfall characteristics of seasons. In years with below average rainfall there are no responses to N fertilizer while significant yield improvements are realized from N when rainfall is not a constraint. This modeling exercise has shown that the planting basin technology has a potential of reducing water and nutrient losses from smallholder crop production systems through reduced surface runoff. The short and long term benefits of this could be improved soil water and nutrient supply to crops during the growing season and the eventual build up of soil fertility on smallholder farmers' fields. Complete crop failure was observed in some years meaning that the smallholder farmer is still at the mercy of rainfall despite the use of planting basin tillage system. The planting basin technology does not offer a complete protection of the farmer against low and poorly distributed in-season rainfall.

CHAPTER 11

Summary and Recommendations

As this study started in the community with low maize production and erratic rainfall one should plot the road travelled and lessons learnt so as to be able to select the direction to head. This study can be used as a springboard for making changes in the household food security in the semi-arid parts of Zimbabwe.

11.1 Smallholder Cropping Systems: The *status quo*

11.1.1 Rainfall pattern

The results from our study showed that total annual rainfall along the Bulawayo to Beitbridge transect has not changed significantly over the past 50 – 74 years (Chapter 4). Our study has shown that total annual rainfall decreases from 584 to 376 mm as one moves from Bulawayo (NR IV) to Beitbridge (NR V). The number of wet days per growing season also decreases from 24 to 12 along the Bulawayo to Beitbridge transect. The growing season is longer in NR IV than V and there is a higher chance of 14 and 21 day dry spells from February onwards during the growing season.

Despite the insignificant changes in total annual rainfall, smallholder farmers in southern Zimbabwe continue to experience reduced crop yields or total crop failure as a result of inadequate soil water supply to crops during the growing season. One of the reasons can be that in-season rainfall distribution is having a bigger negative effect on crop production than the total annual rainfall. The poor rainfall distribution and the heavy rainstorms that are normally followed by long dry spells during the growing season mean that smallholder farmers in the Mzingwane catchment need to make quick decisions on when to plant or apply topdressing fertilizer soon after

rainfall event(s) before soil water is lost through evaporation. A false start of the growing season is sometimes experienced in Gwanda and Insiza districts and this further highlights the need for smallholder farmers to improve on the timing of planting and have a 14-day weather forecast readily available.

In semi-arid districts of southern Zimbabwe some of the strategies that smallholder farmers can use to reduce the impact of in-season rainfall variability include choosing the right crop types and varieties that are recommended for NR IV and V. During the three seasons of experimentation in Gwanda district farmers spoke highly of traditional sorghum variety *Lundende* which they said is more drought tolerant than the open pollinated varieties Macia, SV 2 and SV 4 which were introduced by researchers. Staggering planting dates of maize, sorghum and pearl millet is one strategy smallholder farmers in southern Zimbabwe can use to overcome the false start of the growing season and poor rainfall distribution during the growing season. This means that they stand a better chance of harvesting at least one of the planting dates as they will be different stages of development during any dry spell and so crops will be affected differently. Agronomic practices such as timely and effective weeding, and use of soil fertility amendments in the smallholder cropping systems improves the productivity of the rainfall received during the growing season.

11.1.2 Land size and management

Land sizes vary considerably in Gwanda and Insiza districts where the available arable land per household ranges from less than a hectare in Insiza district to more than 2 ha in Gwanda district (Chapter 6). Management of agricultural land by smallholder farmers in Gwanda and Insiza districts involves conventional ploughing

at the onset of the rains during the October to December period. Ploughing is carried out by donkey or ox drawn conventional plough and ploughing depth achieved ranges between 0.1 and 0.15 m. Ploughing depth is shallower than that recommended by AGRITEX of 0.23-0.25 m because draught animals are often in poor condition during the October to December period. Poor condition of ploughs and the inappropriate setting of the plough results in the shallow ploughing depths achieved by most smallholder farmers. Although winter ploughing is a recommended practice for semi-arid southern Zimbabwe, it is not being practiced by most farmers in the Mzingwane catchment (Chapter 5).

The start of growing season stretches from November to January (Chapter 4), therefore planting of cereals and legumes is done from November to January (Table 11.1). A typical cropping calendar for cereal and legume crops (bambara nut, groundnut and cowpea) on smallholder farms in semi-arid southern Zimbabwe is given in Table 11.1. In Insiza district, smallholder farmers plant maize soon after the first effective rains while in Gwanda district maize, sorghum and pearl millet are planted after the effective rains. Between three to six weeks after planting, depending on household farm power resources, weeding is carried out using hand hoes or with animal drawn cultivators (Chapters 5 and 6; Mbanje *et al.*, 2001). Most often two to three household members provide permanent labour for farming activities such as planting and weeding (Chapter 6). The better resourced households use ox/donkey drawn cultivators for weeding and sometimes hire extra labour during peak periods. Topdressing of cereal crops during January-February period is often delayed because of inadequate soil water for fertilizer application as dry spells occur more frequently during the January-February period (Chapter 4; Chapter 7; Chapter 9a).

Table 11.1. Typical cropping calendar for smallholder cropping systems of semi-arid southern Zimbabwe

Month/Activity	J	A	S	O	N	D	J	F	M	A	M	J
Land preparation												
Planting												
1 st weeding												
Topdressing												
2 nd weeding												
Harvesting												

11.1.3 Livestock sub-system

A smallholder farm in Gwanda and Insiza districts is typified by close interaction and exchanges between crop and livestock sub-systems. The predominant livestock species are cattle, goats, donkeys and chickens (Chapters 5 and 6). Livestock numbers vary considerably from household to household. A well resourced household can own about 40 cattle, 76 goats and 28 donkeys (Chapter 6). A poorly resourced household in both Gwanda and Insiza districts owns only chickens. Our study showed a general decrease in the number of cattle, goats and donkeys per household from 2005 to 2008 (Chapter 6). These changes in numbers of cattle and donkeys imply households in Gwanda and Insiza districts are facing more severe shortages of draught power for ploughing and cultivation. The low resourced households will plough and plant much later given the increased shortage of draught power. There are differences in livestock numbers owned by households in Gwanda and Insiza districts. The households in Gwanda district (NR V) own more livestock than households in Insiza district (NR IV). Cattle and donkeys are sources of draught power and access to draught animal power enables cattle/donkey owners to prepare land and plant during November to January period. Donkeys also play a crucial role in the transport system within both the villages of Gwanda and Insiza districts. Livestock use crop residues from the cropping sub-system as feed - these being either grazed *in situ* or taken to the homestead soon after harvesting for systematic dry season feeding.

11.1.4 Crop sub-system

The predominant cereals grown during summer in southern Zimbabwe are maize, sorghum and pearl millet. Smallholder farmers grow both traditional and hybrid cereal varieties. The open pollinated sorghum varieties grown in Gwanda and Insiza districts include Macia, SV 2 and SV 4. The open pollinated traditional sorghum varieties, grown on a smaller scale than Macia, SV 2 and SV 4, include *Lundende*, *Tsweta* and *Nkotakota* (Chapter 5). The majority of smallholder farmers in Gwanda and Insiza districts of southern Zimbabwe grow traditional pearl millet varieties. Maize varieties are derived from commercial seed houses such as Pannar and Pioneer. In most seasons smallholder farmers plant maize seed retained from the previous season or gain access to cereal and legume seed at seed fairs organised in conjunction with NGOs and AGRITEX.

Legumes are grown to a lesser extent, with groundnuts and bambara nuts being the predominant legume species. Legume production is constrained by lack of seed on both the local (village level) and commercial markets. Therefore legumes are grown on less than 10 % of cropped area during most seasons (Chapters 5 and 6). Lack of legume seed on the local and commercial markets has promoted continued monocropping in both the conventional and CA systems that are being widely promoted in southern Zimbabwe. This could be changed by increasing production of legume seed through contract farming and/or seed multiplication programs organized by NGOs and other agriculture research institutions.

11.1.5 Current soil water and fertility management

The only notable soil water management techniques being used on smallholder farms are graded contours in Insiza district, and dead level contours and infiltration pits in Gwanda district (Chapter 5; Chapter 8). The dead level contours and infiltration pits are being promoted by NGO driven community development projects as the construction of graded contours was mandatory during the pre-independence era. However, these graded contours have hardly been maintained in either Insiza or Gwanda districts. The absence of in-field soil water management techniques on smallholder farms in Gwanda and Insiza districts means there is scope for the wide promotion of planting basins and ripper tillage systems. Smallholder farmers in Insiza district (NR IV) already use both livestock manure and inorganic fertilizer (Chapters 5 and 6). In contrast, only a small proportion of smallholder farmers in Gwanda district (NR V) apply manure and inorganic fertilizer. The strong perception that livestock manure and inorganic fertilizer burn crops needs to be urgently addressed in order to promote use of fertilizer and address the continuation of nutrient mining and low productivity in the smallholder cropping systems of southern Zimbabwe.

11.2 Soil Water and Fertility Management: What Research has Developed

11.2.1 In-situ water and soil fertility management

On-station and on-farm studies were conducted to explore the effect of techniques such as minimum tillage and mulching on soil water dynamics and crop yields. Planting basins reduced surface runoff water losses from cropped fields and were able to collect more rain water at the beginning of cropping season (Chapter 7; Chapter 9a). The higher soil water status at the beginning of the growing season allowed better crop establishment in the basin system compared with single and double

conventional ploughing, and ripper tillage systems. However, our study demonstrated that planting basins on both clay (Matopos) and sandy (On-farm) soils can lead to waterlogging during periods of the growing seasons that experience incessant rains. This suppresses crop growth and could lead to significant yield reductions during seasons when rainfall conditions are favourable to get a crop harvest.

Hand dug planting basins and double spring conventional ploughing, when combined with nitrogen fertilizer ($10-20 \text{ kgNha}^{-1}$) and manure (3 tha^{-1}) increased maize yields, and water use efficiency under semi-arid conditions (Chapter 7). Our study demonstrated that double spring ploughing gives higher crop yield with similar soil fertility inputs than single conventional ploughing, ripper and basin tillage systems (Chapter 7). The on-farm study clearly highlighted the fact that both soil water and fertility management are required at the same time in the smallholder cropping systems of southern Zimbabwe (Chapter 7). The evaluation of the tillage systems promoted over three growing seasons in Gwanda and Insiza districts revealed that smallholder farmers had obtained higher crop yields from the double ploughing system and those with draught animals are prepared to continue using the DP tillage system (Chapter 6). However, the modelling exercise conducted in our study indicated that in the long term total crop failures in seasons with below average rainfall can be experienced under both conventional and basin tillage systems (Chapter 10). The results from the modelling exercise (Chapter 10) and field experimentation (Chapter 7; Chapter 9a) suggest that food deficits will continue as the performance of the new technologies such as planting basins is dependant on the seasonal rainfall pattern. It is critical to carry out a detailed study on in-season rainfall variability patterns and this will assist farmers and researchers in modifying rain and

soil water management technologies that have been developed for semi-arid conditions.

11.2.2 Inter-field soil water management

The current study assessed lateral soil water movement from the dead level contour and infiltration pit into the cropped field (Chapter 8). The findings revealed that dead level contours with infiltration pits capture more rainwater than dead level contours only. Lateral soil water movement from the dead level contour with or without infiltration pit only occur after receiving rainfall event of more than 40 mm. Lateral soil water movement was detected 3 m downslope of the dead level contour with or without infiltration pit (Chapter 8). The dead level contours fed soil water in the middle layers of the 0 – 0.6 m profile studied. Strip cropping along the downslope side of the contour may be a more appropriate way of using the rainwater collected in the contour as soil water only moves 3 m from the dead level contour. There were no significant maize and pearl millet yield differences as distance from the contour increased, suggesting no significant soil water differences particularly in seasons with below average rainfall like 2006/07 and 2007/08.

11.3 What are the Opportunities for Adopting Developed Technologies?

The soil water and fertility management options explored in our study aim at promoting sustainable farming.

11.3.1 Crop yields

Crop yields can increase when smallholder farmers use double ploughing, ripper, planting basins, mulching, crop rotation, inorganic and organic fertilizers (Chapters 7,

9a and 9b). Crop yields also increase if planting and weed control are done on time. Increased crop yields are critical in sub-Saharan Africa where food deficits are experienced even after growing seasons with above average rainfall (Chapter 6). The use of planting basin system offers households without draught power an opportunity to plant on time and consequently achieve crop yields similar to better resourced households (Chapters 7, 9a and 9b). The low resourced households can get similar or even better crop yields by using planting basins than households with draught power in seasons with below average rainfall pattern, giving a lot of hope to vulnerable households in semi-arid environments.

11.3.2 Soil health, water and fertility

In CA systems disturbing the soil only where the seed is to be planted allows physical recovery of the soil on the undisturbed areas. Improvement in soil structure allows better soil conditions for plant roots to be able to explore the whole soil profile for water and nutrients. Minimum tillage and mulching promote increase in organic carbon (Chapter 9c) and a proliferation of soil fauna and flora which play a crucial role in nutrient cycling (Sprent, 2007). Instead of acting as emitters of carbon through release of carbon dioxide, soils under conservation agriculture systems can be sinks of carbon, absorbing carbon dioxide from the atmosphere (Mrabet, 2007; Smith, 2006).

Combining minimum tillage techniques with mulching reduces surface runoff and soil evaporation, and improves infiltration of rainwater into the soil (Chapter 9c; Smith, 2006). The improved soil organic matter status and structure improve the water holding capacity of the soil, potentially making more soil water available to crops. Minimum tillage techniques such as hand dug planting basins and ripping allow more

efficient utilization of farming inputs such as seed, inorganic fertilizer and manure. For example in planting basin system only 10 % of the total land area is dug to insert the seed and fertilizer/manure placement compared to the whole area under the conventional tillage system. Smallholder farmers can therefore apply manure to a large land area through the use of the planting basin system. In addition soil fertility builds up at the permanent planting positions as soil fertility amendments are not spread over the whole field. Soil productivity will eventually improve if the farmers continue to use the planting basin system leading to increased household food security.

11.3.3 Farm labour and energy

Conservation agriculture techniques spread labour demand over a longer time period compared to the conventional farming system. The spread of farm labour enables farmers to carry out the operations such as land preparation, planting and weeding by themselves and on time (Chapter 6). By practicing minimum tillage farmers can reduce time and labour requirements by 30 to 40 % in subsequent years compared to conventional systems (Smith, 2006). In the face of high fossil fuel prices commercial farmers who use mechanized agriculture can substantially reduce their fuel requirements by adopting conservation agriculture practices.

11.4 What are the Constraints to Adoption of the Technologies Developed?

Technologies such as planting basins have high labour demand initially for land preparation and weeding. Farmers normally complain that digging basins is backbreaking in all seasons and weed pressure unbearable particularly in relatively wet seasons. Individual households normally have two to three labour persons

(Chapter 6) and they cannot cope with the labour demand during peak periods. In Gwanda and Insiza districts, our study revealed a slight decrease in the number of people per household between the years 2005 and 2008 (Chapter 6).

New equipment is obviously required when a farmer adopts some of the new technologies. Farmers might find it difficult to plant and weed such fields using traditional hand hoes as observed at Matopos research site during the four seasons of experimentation (Chapters 9a and 9b). In the hyper-inflationary environments prevailing in sub-Saharan countries such as Zimbabwe, availability of agricultural inputs such as fertilizer and seed could be a major stumbling block to adoption of sustainable farming methods. The poor marketing system and low prices offered for agricultural produce by GMB could further curtail adoption of promising technologies by smallholder farmers.

The introduction of new technologies also requires a change of the mindset of a farmer who might consider new ways of farming more risky. The farmer's mindset could further be aggravated if new technologies are not well explained to them. However, the farmers' confidence could grow if they are accepted as equal partners and experts in their own environment (Steiner, 2007). Lack of technical support from poorly resourced agricultural extension departments, like is the case in Zimbabwe now, could retard the adoption of promising technologies by smallholder farmers.

11.5 The way forward

A wide range of promising technologies are already available for uptake by the smallholder farmers. These technologies need to be promoted on a wider scale by all

stakeholders involved in research and development. During the promotion process NGOs and researchers, in conjunction with experienced extension staff, should continue training new farmer groups and extension officers. During the training sessions producers of agriculture inputs such as seed and fertilizers should be invited to participate so that they become aware of what is expected of them in the development of smallholder agriculture. A study by ICRISAT and the Zimbabwe Fertilizer Company (ZFC) showed that smallholder farmers now prefer the 10-20 kg fertilizer pack sizes to the traditional 50 kg which has become difficult to transport because of the poor transport system in rural areas. The provision of extension materials such as manuals, flyers and bulletins translated into vernacular is critical for adoption of promising technologies. These extension materials should continue to be developed by researchers, extension and NGOs, and distributed well in advance before the onset of the rainy season.

Capacity building of farmers is critical for the uptake of the promising technologies that still lie 'idle' in the farmers' basket of options. At some point during the wide scale promotion of the promising technologies, farmer to farmer extension could play a crucial role with the extension and research agents playing a facilitator's role in the process. For example in all districts in Zimbabwe where CA systems are being promoted, there are farmers who have been hosting CA demonstrations for two to three seasons. These experienced farmers could lead farmer groups in experimenting with the technologies such as planting basins, ripper, the use of manure and inorganic fertilizer. During the experimentation process the farmers could make adjustments to certain components of the technologies to suit their circumstances. They might even start with just a few components of a technology and gradually include all the other

aspects as they gain experience and other necessary resources. For example the CA systems being promoted in semi-arid districts of Zimbabwe encourage the use of mulch (Chapters 9a and 9b) in an environment where livestock plays a bigger role in the livelihoods of farming families. Mulching can be adopted at a later stage when more crop biomass is being produced. Smallholder farmers can even test the performance of their traditional crop varieties in CA systems especially now when seed availability is one of the major challenge in the smallholder farming sector. Field days and exchange visits provide an opportunity for agriculture information dissemination as extension, researchers and producers of agriculture inputs interact with farmers and other stakeholders involved in agriculture development.

11.6 Future research

The analysis of 50 to 74 year rainfall data revealed that there is no significant decline in total annual rainfall nor any changes in the start and end time of growing seasons in the semi-arid southern part of Zimbabwe (Chapter 4). However, the mid-season dry spells continue to cause reduced yields and total crop failure in the smallholder farming sector. There is need for a detailed study on within season rainfall variability in order to come up with more robust ways of reducing the risk of crop failure in smallholder agriculture of the semi-arid environments. The droughts and dry spells that continue to be experienced in southern Zimbabwe point to the need for making more use of seasonal forecasts that are issued every September before the onset of the rains. The seasonal forecast information should get to the farmers in a simplified format and well before the onset of the rains so that they can use it to make appropriate farming decisions together with the type of information found in this thesis.

The study on the tillage and mulching effects on maize, cowpea and sorghum crop production conducted at Matopos and Lucydale sites used a blanket 20 kg ha⁻¹ nitrogen rate. There is need to consider a range of nitrogen application rates as the 20 kg ha⁻¹ might not be adequate in some seasons particularly where immobilization of the applied nitrogen takes place because of the surface applied mulch. The maize stover applied as mulch adds a lot of carbon that can result in N immobilization such that farmers fail to benefit from the use of the mulch in their cropping system.

There is need to carry out a more detailed study on soil water dynamics from dead level contours with current design of the contours and also with other possible designs. The results from this study on dead level contours and infiltration pits indicated lateral water movement from the contours after rainstorms of more than 40 mm. It might be useful to determine the threshold rainstorm sizes for meaningful lateral movement of soil water into the field from dead level contour with or without infiltration pit. There is need to determine the effect of different sizes of the infiltration pit and positions along the dead level contour. Information generated from such studies can be used in future modification of the current design of the dead level contours and infiltration pits. The results from simulation of the long term impact of planting basins on crop productivity in smallholder systems suggest that the APSIM model still requires more rigorous calibration for the planting basin tillage system.

References

- Abiven, S. and Recous, S. 2007. Mineralization of crop residues on the soil surface or incorporated in the soil under controlled conditions. *Biology and Fertility of Soils*, 43: 849-852.
- AGRITEX (undated). A guide for farmers on good land husbandry. 64pp. www.uz.ac.zw/agriculture/cropscience/CD/gff/handplanting.pdf.
- AGRITEX (Department of Agricultural Technical and Extension Services). 1990. Agro-climatology Applied to Crop Production in Zimbabwe. Department of Agricultural Technical and Extension Services, Ministry of Lands, Agriculture and Rural Resettlement. Harare. 26pp.
- Ahmed, M.M., Rohrbach, D.D., Gono, L., Mazhangara, E., Mugwira, L., Masendeke, D.D. and Alibaba, S. 1997. Soil fertility management in communal areas of Zimbabwe: Current practices, constraints and opportunities for change. Results of a diagnostic survey. Southern and Eastern African Region. Working Paper N°6. 30pp.
- Alvord, E.D. 1936. Annual report to the agriculturist. Native Department, Harare. 35pp.
- Al-Qinna, M. I. and Abu-Awwad, A. M. 2001. Wetting patterns under trickle source in arid and semi-arid soils with surface crust. *Journal of Agricultural Engineering Research*, 80 (3): 301-305.
- Amato, M. and Ritchie, J.T. 2002. Spatial distribution of roots and water uptake of maize (*Zea mays* L.) as affected by soil structure. *Crop Science*, 42: 773-780.
- Anderson, I.P., Brinn, P.J., Moyo, M. and Nyamwanza, B. 1993. Physical Resource Inventory of Communal Lands of Zimbabwe. Natural Resources Institute Bulletin 60, London. 186pp.
- Anderson, J.M. and Ingram, J.S.I. 1993. Tropical Soil Biology and Fertility. A Handbook of Methods. 2nd Edition. C.A.B. International, Wallingford, UK, 221pp.
- Anjichi, V.E., Mauyo, L.W. and Kipsat, M.J. 2007. The effect of socio-economic factors on a farmer's decision to adopt farm soil conservation measures. An application of the multivariate logistic analysis in Butere/Mumias district, Kenya. pp915-919. In: Bationo, A., Waswa, B., Kihara, J. and Kimetu, J. (eds.). *Advances in*

Integrated Soil Fertility Management in Sub-Saharan Africa. Springer Publishers, Dordrecht, The Netherlands.

Archer, J. 1988. Crop Nutrition and Fertiliser Use. Farming Press Ltd. Suffolk

Arshad, M.A., Franzluebbers, A.J. and Azooz, R.H. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. *Soil and Tillage Research*, 53: 41-47.

Aviad, Y., Kutiel, H. and Lavee, H. 2004. Analysis of beginning, end and length of the rainy season along a Mediterranean arid climate transect for geomorphic purposes. *Journal of Arid Environments*, 59: 189-204.

Azooz, R.H. and Arshad, M.A. 1996. Soil infiltration and hydraulic conductivity under long term no-tillage and conventional tillage systems. *Canadian Journal of Soil Science*, 76: 143-152.

Barron, J. and Rockstrom, J. 2003. Water Harvesting to Upgrade Smallholder Farming: Experiences From On-farm Research in Kenya and Burkina Faso. RELMA/SIDA, Stockholm University, Sweden.

Barron, J. 2004. Dry spell mitigation to upgrade semi-arid rainfed agriculture: Water harvesting and soil nutrient management for smallholder maize cultivation in Machakos, Kenya. Ph.D Thesis in Natural Resources Management. Department of Systems Ecology. Stockholm University. Sweden.

Baudeon, F., Mwanza, H.M., Triomphe, B. and Bwalya, M. 2007. Conservation agriculture in Zambia: a case study of Southern Province. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations. 57pp. www.fao.org.

Belder, P., Twomlow, S. and Hove, L. 2007. Early evidence of improved soil quality with conservation farming under smallholder farming conditions in Zimbabwe. Paper presented at the ICID conference, November 2007, Johannesburg, South Africa. 15pp.

Bescansa, P., Imaz, M. J., Virto, I., Enrique, A. and Hoogmoed, W. B. 2006. Soil water retention as affected by tillage and residue management in semi-arid Spain. *Soil and Tillage Research*, 87: 19-27.

- Bhattacharyya, R., Prakash, V., Kundu, S. and Gupta, H.S. 2006. Effect of tillage and crop rotations on pore size distribution and soil hydraulic conductivity in sandy clay loam soil of the Indian Himalayas. *Soil and Tillage Research*, 86: 129-140.
- Bindraban, P.S., Stoorvogel, J.J., Jansen, D.M., Vlaming, J. and Groot, J.J.R. 2000. Land quality indicators for sustainable land management: Proposed method for yield gap and soil nutrient balance. *Agriculture, Ecosystems and Environment*, 81(2): 103-112.
- Bissett, M.J. and O'Leary, G.J. 1996. Effects of conservation tillage and rotation on water infiltration in two soils in south-eastern Australia. *Australian Journal of Soil Research*, 34: 299-308.
- Bosch, H, van den., Gitari, J.N., Ogaro, V.N; Maobe, S. and Vlaming, J. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) 111. Monitoring nutrient flows and balance in three districts in Kenya. *Agriculture, Ecosystems and Environment*, 71(1/3): 63-80.
- Botha, J.J., van Rensburg, L.D., Anderson, J.J., Hensley, M., Macheli, M.S., van Staden, P.P., Kundhlande, G., Groenewald, D.G. and Baiphethi, M.N. 2003. Water conservation technologies on small plots in semi-arid areas to enhance rainfall use efficiency, food security and sustainable crop production. WRC Report N^o 1176/1/03. 338pp.
- Bouman, A. B. M., 2007. A conceptual framework for the improvement of crop water productivity at different spatial scales. *Agriculture Systems*, 93: 43-60.
- Bruneau, P.M.C. and Twomlow, S.J. 1999. Hydrological and physical responses of a semi-arid sandy soil to tillage. *Journal of Agricultural Engineering Research*, 72: 385-391.
- Cakir, R., 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research*, 89: 1-16.
- Carsel, R.F. and Parrish, R.S. 1988. Developing joint probability distributions of soil water retention characteristics. *Water Resources Research*, 24: 755-769.
- Carter, M.R. 1996. Characterization of soil physical properties and organic matter under long-term primary tillage in a humid climate. *Soil and Tillage Research*, 38: 251-263.

- Chakraborty, D., Nagarajan, S., Aggarwal, P., Gupta, V.K., Tomar, R.K., Garg, R.N., Sahoo, R.N., Sarkar, A., Chopra, U.K., Sarma, K.S.S. and Kalra, N. 2008. Effect of mulching on soil and plant water, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agricultural Water Management*, doi:10.1016/j.agwat.2008.06.001.
- Chibudu, C., Chiota, G., Kandiros, E., Mavedzenge, B., Mombeshora, B., Mudhara, M., Murimbarimba, F., Nasasara, A. and Scoones, I. 2001. Soils, livelihoods and agricultural change: The management of soil fertility in the communal lands of Zimbabwe. pp116-163. In: Scoones, I. (ed). *Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa*. Earthscan Publication Ltd., London.
- Chibulu, B. 2007. Effect of rainfall variability on crop yield under semi-arid conditions at sub-catchment level. M.Sc. Thesis. Department of Civil Engineering, University of Zimbabwe, Harare. 77pp.
- Chiduza, C., 1995. Analysis of rainfall data and their implication on crop production: A case of Northern Sebungwe. *Zimbabwe Journal of Agricultural Research*, 33 (2): 175-189.
- Chiduza, C. 1997. Effect of between-row and within-row spacing on yield of sorghum variety SV 2 in the Zambezi valley of Zimbabwe. *Zimbabwe Journal of Agricultural Research*, 35(2): 129-140.
- Chikowo, R., Mapfumo, P., Nyamugafata, P. and Giller, G.E. 2004. Maize productivity and mineral N dynamics following different soil fertility management practices on a depleted sandy soil in Zimbabwe. *Agriculture, Ecosystems and Environment*, 102:119-131.
- Chuma, E. 1993. Effects of tillage on erosion-related soil properties of a sandy soil in semi-arid Zimbabwe. In Kronen, M. (Ed.). *Proceedings of the Fourth Annual Scientific Conference, SADC Land and Water Management Research Programme, SACCAR, Gaborone, Botswana*.
- Chuma, E. and Haggmann, J. 1998. Development of conservation tillage techniques through combined on-station and participatory on-farm research. In: Blume, H-P.; Eger, H.; Flieischhauer, E; Hebel, A.; Reij, C and Steiner, K.G. (Eds.).

Towards Sustainable Land Use. Furthering Cooperation Between People and Institutions Vol. II. Advances in Geoecology 31. Catena Verlag GMBH Reiskirchen, Germany.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A. and Whetton, P. 2007. Regional climate projections. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

CIMMYT, 1993. Annual Report November 1992 - October 1993. CIMMYT-Zimbabwe. 57pp.

Clay, E., Bohn, L., de Armas, E.B., Kabambe, S. and Tchale, H. 2003. Malawi and southern Africa: Climatic variability and economic performance. Disaster Management Facility. Working Paper N° 7. World Bank, Washington DC. March 2003. 112pp.

CONTILL, 1998. Conservation tillage for sustainable crop production systems. Documented Outputs of the AGRITEX/GTZ Project. Annotated bibliography 1988-1996. Institute of Agricultural Engineering, Harare.

Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B. Shiferaw, B. and Twomlow, S. 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment*, 126: 24-35.

Das, D. K. and Chopra U. K. 1988. Soil water movement, balance and its use by crops as influenced by soil physical conditions. pp231-254. In: Somani L. L. (ed.). *Soil physical conditions and crop growth*, Monograph. Geo-Environ Academia and Divyajyoti Prakashan, Shatri Nagar, India. 254pp.

Decagon Devices 2007. Minidisk infiltrometer. User's Manual, version 4. 18pp.

- Defoer, T., Budelman, A., Toulmin, C., and Carter, S.E. 2000. Building Common Knowledge. A Resources Guide for Participatory Learning and Action Research. In: Defoer, T. and Budelman, A. (Eds.), *Managing Soil Fertility in the Tropics: A Resource Guide for Participatory Learning and Action Research*. Royal Tropical Institute (KIT), Amsterdam, The Netherlands. 208pp.
- Defoer, T. 2002. Learning about methodology development for integrated soil fertility management. *Agricultural Systems*, 73: 57-81.
- Delve, R.J. and Probert, M.E. 2004. Modelling nutrient management in tropical cropping systems. Australian Centre for International Agricultural Research (ACIAR), Canberra. ACIAR Proceedings, N° 114. 138pp. www.aciar.gov.au.
- Dennett, M.D. 1987. Variation of rainfall: the background to soil and water management in dryland regions. *Soil, Use and Management*, 3(2): 47-51.
- Dexter, A.R. 2004. Soil physical quality. Part 1. Theory, effects of soil texture, density and organic matter, and effects on root growth. *Geoderma*, 120: 201-214.
- Dhliwayo, H.H., Mabasa, S., Twomlow, S.J. and Riches, C.R. 1995. The effects of weeding methods and water conservation on weed populations in dryland maize. Brighton Crop Protection Conference – Weeds, November 1995. Farnham, Surrey, UK: BCPC., 1: 207-212.
- Diagana, B. 2003. Land degradation in sub-Saharan Africa: What explains the widespread adoption of unsustainable farming practices? Department of Agricultural Economics, Montana State University, Bozeman, USA. <http://www.tradeoffs.montana.edu/pdf/SD-BD.pdf>.
- Dimes, J. and Malherbe, J. 2006. Climate variability and simulation modeling – challenges and opportunities. In: Mgonja, M.A., Waddington, S., Rollin, D. and Masenya, M. (eds.). *Livelihoods in the Limpopo: CGIAR Challenge Program on Water and Food Project N° 1. Increased food security and income in the Limpopo basin through intergrated crops, soil fertility and water management options and links to markets*. Proceedings of the CPWFPN 1 Inception workshop, 25-27 January 2005. Polokwane, South Africa. 132pp.
- Dixon, W.J. and Massey, F.J. 1983. *Introduction to Statistical Analysis*. McGraw-Hill International Book Co. Ltd., Japan. 678pp.

- Dryland Farming Research Scheme (DLFRS) Phase III. 1985. Final report, 6. Digest of research findings. Overseas Development Administration, London, UK.
- ECAF, 1999. Conservation agriculture in Europe: Environmental, Economic and Policy Perspectives. Report No1. European Conservation Agriculture Federation. 24pp. <http://www.ecaf.org>.
- Ehlers, W., 1975. Observations on earthworm channels and infiltration on tilled and untilled loess soil. *Soil Science*, 119: 242-249.
- Erenstein, O. 2002. Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil and Tillage Research*, 67: 115-133.
- FAO. 1998. World Reference Base for Soil Resources. World Soil Resources Report 84. Rome.
- FAO, 2006. Fertilizer use by crop in Zimbabwe. Land and Plant Nutrition Services. Land and Water Development Division. Food and Agriculture Organisation of the United Nations, Rome.
- Fatondji, D., Martius, C., Biielders, C.L., Vlek, P.L.G., Bationo, A. and Gerard, B. 2006. Effect of planting technique and amendment type on pearl millet yield, nutrient uptake and water use on degraded land in Niger. *Nutrient Cycling in Agroecosystems*, 76: 203-217.
- Freund, J.E. 1979. Modern Elementary Statistics. 5th Edition. Prentice-Hall, INC., New Jersey. 510pp.
- Friedrich, T. and Kienzie, J. 2007. Conservation agriculture: Impact on farmers' livelihoods, labour, mechanization and equipment. pp25-36. In: Stewart, B.A., Asfary, A.F., Belloum, A., Steiner, K. and Friedrich, T. (eds.). Proceedings of International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas. 7-9 May 2007, Damascus, Syria.
- Gaiser, T., de Barros, I., Lange, F.M. and Williams, J.R. 2004. Water use efficiency of a maize/cowpea intercrop on a highly acidic tropical soil as affected by liming and fertilizer application. *Plant and Soil*, 263(1): 165-171.

- Gicheru, P.T., Gachene, C.K.K., Mbuvi, J.P. and Wanjogu, S.N. 2003. Effects of soil management practices and tillage systems on soil water conservation and maize yield on a sandy loam in semi-arid Kenya. pp18-24. In: Beukes, D., de Villiers, M., Mkhize, S., Sally, H. and van Rensburg, L. (eds.). Proceedings of the Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in sub-Saharan Africa (WCT). Bloemfontein, South Africa. 8-11 April 2003.
- Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W. and Mafongoya, P.L. 1997. Building soil nitrogen capital in Africa. pp151-192. In: Buresh, J.R., Sanchez, P.A. and Calhoun, F. (eds.). Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publication N° 51.
- Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P. 2008. Conservation agriculture and smallholder farming in Africa: The heretic's view. Paper submitted to the Field Crops Research journal, 10/7/2008.
- Głab, T. and Kulig, B. 2008. Effect of mulch and tillage system on soil porosity under wheat (*Triticum aestivum* L.). Soil and Tillage Research, 99: 169–178.
- Grant, P., Meikle, G.J. and Mills, W.R. 1979. A comparison of plough types and depths of annual ploughing for maize monoculture with varied manuring. Rhodesian Journal Agricultural Research, 17: 99-123.
- Grant, P.M. 1981. The fertilization of sandy soils in peasant agriculture. Zimbabwe Agricultural Journal, 78: 169-175.
- Gregory, P.J. 1984. Water availability and crop growth in arid regions. Outlook on Agriculture, 13(4): 208-215.
- Guzha, A. C. 2004. Effect of tillage on soil microrelief, surface depression storage and soil water storage. Soil and Tillage Research 76: 105-114.
- Hadas, A., Rawitz, E., Etkin, H. and Margolin, M. 1994. Short-term variations of soil physical properties as a function of the amount of C/N ratio of decomposing cotton residues. I. Soil aggregation and aggregate tensile strength. Soil and Tillage Research, 32: 183–198.

- Haggblade, S. and Tembo, G. 2003. Conservation farming in Zambia. Conference paper N°11. p18. Paper presented at the IFPRI, NEPAD, CTA conference, Successes in African Agriculture. Pretoria, South Africa. 1-3 December 2003.
- Hagmann, J. 1994. Lysimeter measurements of nutrient losses from a sandy soil under conventional-till and ridge-till. pp305-310. In: Jensen, B.E., Schjonning, P., Mikkelsen, K.B. (Eds.). Soil Tillage for Crop Production and Protection of the Environment. Proceedings of the 13th International Conference, International Soil Tillage Research Organisation (ISTRO), Aalborg, Denmark.
- Hall, A.E. 2004. Breeding for adaptation to drought and heat in cowpea. *European Journal of Agronomy*, 21: 447-454.
- Halvorson, A.D., Wienhold, B.J. and Black, A.L. 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. *Soil Science Society of America Journal*, 66: 906-912.
- Hanks, R.J. and Ashcroft, G.L. 1980. Applied soil physics: soil water and temperature applications. Advanced Series in Agricultural Sciences 8. Springer-Verlag. 159pp.
- Hatfield, J. L., Sauer, T. J. and Prueger, J. H. 2001. Managing soils to achieve greater water use efficiency: A review. *Agronomy Journal*, 93: 271-280.
- Hayes, M.J., Svoboda, M.D., Wilhite, D.A. and Vanyarkho, O.V. 1999. Monitoring the 1996 drought using the Standardized Precipitation Index. *BAMS*, 80: 429-438.
- Heal, O.W., Anderson, J.M. and Swift, M.J. 1997. Plant litter quality and decomposition: A historical overview. pp3-30. In: Cadisch, G. and Giller, K. (eds.). Driven by nature: Plant litter quality and decomposition. CAB Publishing, Wallingford.
- Heinrich, G. 1989. Report on Farmer Testing Groups (ATIP), Francistown, 1988-1989. Presented at Annual Crops Seminar, September 1989, Sebele, Botswana.
- Henao, J. and Baanante, C. 2006. Agricultural production and soil mining in Africa: Implications for resource conservation and policy development. International Fertilizer Centre for Soil Fertility and Agricultural Development. Muscle Shoals, Alabama, USA. <http://www.africafertilizersummit.org>.

- Hikwa, D., Nyathi, P., Mugwira, L.M., Mudhara, M. and Mushambi, C.F. (Eds.). 2001. Integrated Soil Fertility Development for Resource-poor Farmers in Zimbabwe: The Research and Development Strategy Beyond 2001. Department of Research and Specialist Services (DRSS). Harare. 48pp.
- Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: Reviewing evidence. *Agriculture, Ecosystems and Environment*, 103: 1-25.
- Homann, S., van Rooyen, A., Moyo, T. and Nengomasha, Z. 2007. Goat production and marketing: Baseline Information for Semi-Arid Zimbabwe. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bulawayo, Zimbabwe. 77pp.
- Hove, L. 2006. Agricultural technology transfer under Relief and Recovery Programs in Zimbabwe: Are NGOs Meeting the Challenge? Briefing Note N^o 6. ICRISAT-Bulawayo. September 2006.
- Hudson, D.A. and Jones, R.G. 2002. Simulation of present day and future climate over southern Africa using HadAM3H. Hadley Centre Technical Note 38. 37pp.
- Hughes, O. and Venema, J.H. (eds.). 2005. Intergrated soil, water and fertility management in semi-arid Zimbabwe. Farmer Field Schools Manual, vol. 1. Harare, Zimbabwe:FAO. ftp://ftp.fao.org/agl/agll/docs/ffsfm_zim.pdf.
- Hulme, M. and Sheard, N. 1999. Climate change scenarios for Zimbabwe. Climatic Research Unit, Norwich, UK. 6pp. <http://www.cru.uea.ac.uk>.
- Hussein, J. 1987. Agro-climatological analysis of growing season in natural regions III, IV and V of Zimbabwe. In: AGRITEX/GTZ. Proceedings of a Workshop on Cropping in Semi-arid Areas of Zimbabwe. 24-28 August 1987, Harare. AGRITEX/GTZ.
- Jackson, I.J. 1977. Climate, Water and Agriculture in the Tropics. Longman Inc., New York. 248pp.
- Kanemasu, E.T., Stewart, J.I., van Donk, S.J. and Virmani, S.M. 1990. Agroclimatic approaches for improving agricultural productivity in semi-arid tropics. *Advances in Soil Science*, 13: 273-309.

- Keating, B.A., Carberry, P., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verbur, K., Snow, V., Dimes, J., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M. and Smith, C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy*, 18: 267-288.
- Klaij, M.C. and Vauchad, G. 1992. Seasonal water balance of a sandy soil in Niger cropped with pearl millet, based on profile moisture measurements. *Agricultural Water Management*, 21: 313-330.
- Klute, A. 1986. Water retention: Laboratory methods. In Klute, A. (Ed.). *Methods of Soil Analysis, Part 1*. American Society of Agronomy, Inc., Madison.
- Konig, H. and Varma, A. 2006. *Intestinal Micro-organisms of Termites and Other Invertebrates*. Springer Publishers. 483pp.
- Le Barbel, L., Lebel, T. and Tapsoba, D. 2002. Rainfall variability in West Africa during the years 1950–90. *Journal of Climatology*, 15: 187-202.
- Lee, B. 1993. *Escaping From Hunger: Research to Help Farmers in Semi-arid Kenya to Grow Enough Food*. ACIAR Monograph N^o. 23. ACIAR. 52pp.
- Liebig, M.A., Tanaka, D.L. and Wienhold, B.J. 2004. Tillage and cropping effects on soil quality indicators in the Northern Great Plains. *Soil and Tillage Research*, 78:131-141.
- Lipic, J., Kus, J., Slowinska-Jurkiewicz, A. and Nosalewicz, A. 2005. Soil porosity and water infiltration as influenced by tillage methods. *Soil and Tillage Research*, 89: 210-220.
- Love, D., Twomlow, S., Mupangwa, W., Van der Zaag, P. and Gumbo, T. 2006. Implementing the millennium development food security goals – Challenges of the southern African context. *Physics and Chemistry of the Earth*, 31: 731-737.
- Love, D., Uhlenbrook, S., Twomlow, S. and van der Zaag, P. 2008. Changing rainfall and discharge patterns in the northern Limpopo Basin, Zimbabwe. *European Geophysical Union General Assembly*, Viena, Austria, April 2008. http://www.worldwaterweek/stockholmwatersymposium/Abstract_volume_06/workshop_9.htm.

- Maddonni, G.A., Otegui, M.E. and Bonhomme, R. 1998. Grain yield components in maize. II. Post silking growth and kernel weight. *Field Crops Research*, 56: 257-264.
- Mandiringana, O.T., Mabi, M. and Simalenga, T.E. 2003. The potential of three water conservation technologies for adoption and use by communal farmers in Eastern Cape. pp56-59. In: Beukes, D., de Villiers, M., Mkhize, S., Sally, H. and van Rensburg, L. (eds.). *Proceedings of the Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in sub-Saharan Africa*. Bloemfontein, South Africa. 8-11 April 2003.
- Mapfumo, P. and Mtambanengwe, F. 1998. Nutrient mining in maize-based systems of rural Zimbabwe. In: EARO/CIMMYT, 1998. *Maize Production Technologies for the Future: Challenges and Opportunities*. The Sixth Eastern and Southern Africa Regional Maize Conference held in Addis Ababa, Ethiopia. 21-25 September 1998. Program and Abstracts. EARO/CIMMYT.
- Mapfumo, P. and Giller, K.E. 2001. Soil fertility management strategies and practices by smallholder farmers in semi-arid areas of Zimbabwe. International Crops Research Institute for the Semi Arid Tropics (ICRISAT) and Food and Agriculture Organization of the United Nations (FAO), Bulawayo, Zimbabwe. 60pp.
- Masikati, P. 2006. Tillage and manure interactions under dryland cropping in semi-arid Zimbabwe. Department of Soil Science and Agricultural Engineering, University of Zimbabwe, Harare, Zimbabwe. M.Phil. thesis. 101pp.
- Masvaya, E., Mupangwa, W. and Twomlow, S. 2008. Rainfall variability impacts on farmers' management strategies and crop yields. Water and sustainable development for improved livelihoods. 9th WaterNet/WARFSA/GWP-SA symposium, 29-31 October 2008, Johannesburg, South Africa.
- Mbanje, E., Twomlow, S. J., and O'Neill, D. H. 2001. Evaluation of animal-drawn weeders for smallholder maize production in Zimbabwe. In "Weeds 2001" *Proceedings of the BCPC Conference*, 12-15 November 2001, Brighton, UK, 2: 913-918.

- Mellis, D.A., Bruneau, P.M.C., Twomlow, S.J. and Morgan, R.P.C. 1996. Field assessment of crusting on tilled sandy clay loam. *Soil, Use and Management*, 12: 72-75.
- Moreno F., Pelegrh F., Fernindez J.E. and Murillo, J.M. 1997. Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. *Soil and Tillage Research*, 41: 25-42.
- Moroke, T.S., Schwartz, R.C., Brown, K.W. and Juo, A.S.R. 2005. Soil water depletion and root distribution of three dryland crops. *Soil Science Society of America Journal*, 69: 197-205.
- Morse, K. 1996. A Review of Soil and Water management Research in Semi-Arid Areas of Southern and Eastern Africa. Chatham, UK. Natural Resources Institute. UK.
- Motsi, K.E., Chuma, E. and Mukamuri, B.B. 2004. Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. *Physics and Chemistry of the Earth*, 29: 1069-1073.
- Moyo, M. 2001. Representative soil profiles of ICRISAT research sites. Chemistry and Soil Research Institute. Soils Report N°A666. AREX, Harare, Zimbabwe, 97pp.
- Moyo, R., Love, D., Mul, M., Twomlow, S. and Mupangwa, W. 2006. Impact and sustainability of drip irrigation kits in 54 the semi-arid Lower Mzingwane Subcatchment, Limpopo Basin, Zimbabwe. *Physics and Chemistry of the Earth*, 31: 885-892.
- Mrabet, R. 2007. Lasting benefits from no-tillage systems: Erosion control and soil carbon sequestration. pp77-92. In: Stewart, B.A., Asfary, A.F., Belloum, A., Steiner, K. and Friedrich, T. (eds.). *Proceedings of International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas*. 7-9 May 2007, Damascus, Syria.
- Mtambanengwe, F. and Mapfumo, P. 2005. Organic matter management as an underlying cause for soil fertility gradients on smallholder farms in Zimbabwe. *Nutrient Cycling in Agroecosystems*, 73: 227-243.
- Mubonderi, T. 1999. Cattle manure and inorganic fertilizer management for dryland maize production in the smallholder sector of Zimbabwe. M.Phil. Thesis.

Department of Crop Science, University of Zimbabwe, Harare, Zimbabwe.
126pp.

- Mugabe, F. 2004. Evaluation of the benefits of infiltration pits on soil moisture in semi-arid Zimbabwe. *Journal of Agronomy*, 3: 188-190.
- Muller-Samann, K.M. and Kotschi, J. 1994. Sustaining growth: Soil fertility management in tropical smallholdings. GTZ/CTA, Margraf Verlag. 486pp.
- Mulumba, L.N. and Lal, R. 2008. Mulching effects on selected soil physical properties *Soil and Tillage Research*, 98: 106-111.
- Mupangwa, W., Love, D. and Twomlow, S.J. 2006. Soil-water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe. *Physics and Chemistry of the Earth*, 31: 893-900.
- Mupangwa, W., Twomlow, S., Walker, S. and Hove, L. 2007. Effect of minimum tillage and mulching on maize (*Zea mays* L.) yield and water content of clayey and sandy soils. *Physics and Chemistry of the Earth*, 32: 1127-1134.
- Mupangwa W., Twomlow S. and Walker S. 2008. The influence of conservation tillage methods on soil water regimes in semi-arid southern Zimbabwe. *Physics and Chemistry of the Earth*, 33: 762-767.
- Mwenge Kahinda, J.M. 2004. Water productivity and yield gap analysis of water harvesting systems in the semi-arid Mzingwane catchment, Zimbabwe. M.Sc. thesis, Water Resources Engineering and Management Programme, University of Zimbabwe. 124pp.
- Ncube, B. 2007. Understanding cropping systems in semi-arid environments of Zimbabwe: Options for soil fertility management. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands. 155pp.
- Ncube, B., Dimes, J.P., Twomlow, S., Mupangwa, W. and Giller, K.E. 2007. Raising the productivity of smallholder farms under semi-arid conditions by use of small doses of manure and nitrogen: A case of participatory research *Nutrient Cycling in Agroecosystems*, 77: 53-67.
- Ncube, B., Twomlow, S., van Wijk, M.T., Dimes, J.P. and Giller, K.E. 2007. Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in south-western Zimbabwe. *Plant and Soil*, 299: 1-15.

- Ncube, B., Dimes, J.P., van Wijk, M., Twomlow, S. and Giller, K. 2008. Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in south-western Zimbabwe: Unravelling the effects of water and nitrogen using a simulation model. *Field Crops Research*, doi:10.1016/j.fcr.2008.08.001.
- NeSmith, D.S. and Ritchie, J.T. 1992. Effects of soil water deficits during tassel emergence on development and yield component of maize (*Zea mays* L.). *Field Crops Research*, 28: 251-256.
- Ngwenya, T.P. 2006. Effect of land degradation from grazing pressure on rangeland hydrology. MSc. Thesis. Department of Civil Engineering, University of Zimbabwe. 57pp.
- Nhamo, N. 2003. The effects of combining cattle manure and inorganic nitrogen fertilizer on sandy soils in Zimbabwe. M.Phil. Thesis. Department of Soil Science and Agricultural Engineering, University of Zimbabwe, Harare, Zimbabwe. 149pp.
- Nhamo, N., Mupangwa, W., Siziba, S., Gatsi, T. and Chikazhunga, D. 2003. The role of cowpea (*Vigna unguiculata* L.) and other grain legumes in the management of soil fertility in the smallholder farming sector of Zimbabwe. In: Waddington, S.R. (Ed.). *Grain Legume and Green Manures for Soil Fertility in Southern Africa: Taking Stock of progress*. Proceedings of a conference held 8-11 October 2002 at Leopard Rock Hotel, Vumba, Zimbabwe. Soil FertNet and CIMMYT-Zimbabwe, Harare, Zimbabwe. 246pp.
- Nhamo, N. 2007. The contribution of different fauna communities to improved soil health: A case of Zimbabwean soils under conservation agriculture. Ph.D. Thesis. University of Bonn. 131pp.
- Nonner, J. 1997. Principles of Hydrogeology. IHE Lecture Note. IHE. Delft, The Netherlands.
- Northwood, P. J. and McCartney, J. C. 1971. The effect of different amounts of cultivation on the growth of maize on some soil types in Tanzania. *Tropical Agriculture (Trinidad)*, 48: 25-33.
- Nyagumbo, I. 1997. Effects of tillage systems on soil physical properties with special reference to infiltration, bulk density and organic carbon. *African Crop Science Conference Proceedings*, 3: 359-368.

- Nyagumbo, I. 2002. The effect of three tillage systems on seasonal water budgets and drainage of two Zimbabwean soils under maize. Ph.D. Thesis, Department of Soil Science and Agricultural Engineering, University of Zimbabwe. 251pp.
- Nyagumbo, I. 2007. A review of experiences and developments towards conservation agriculture and related systems in Zimbabwe. pp345-372. In: Goddard, T., Zoeibisch, M., Gan, Y., Ellis, W., Watson, A. and Somatpanit, S. (eds.). No-Till Farming Systems. Special Publication Number 3. World Association of Soil and Water Conservation.
- Nyakatawa, E.Z., Brown, M., and Maringa, D. 1996. Maize and sorghum yields under tied ridges of fertilised sandy soils in semi-arid south-east lowveld of Zimbabwe. *African Crop Science Journal*, 4: 197-206.
- Nyamangara, J. and Mpofu, S. E. 1996. Soil pH and lime requirement for high potential communal areas of Zimbabwe. *Journal of Applied Science in Southern Africa* 2, 77-81.
- Nyamangara, J., Mugwira, L.M. and Mpofu, S.E. 2000. Soil fertility status in the communal areas of Zimbabwe in relation to sustainable crop production. *Journal of Sustainable Agriculture*, 16(2): 15-29.
- Nyamapfene, K. 1991. *Soils of Zimbabwe*, NeHanda Publishers, Harare, Zimbabwe. 179pp.
- Nyamudeza, P., Mazhangara, E. and Kamba, E. 1992. Adoption of tied furrow technique and effects of the technique and previous crop on residual moisture and yields of sorghum and maize. Paper Presented at the Annual Review Meeting of the IBSRAM Vertisol Management Network in Africa. June, 1992. Accra, Ghana. pp69-81.
- Nyamudeza, P. 1993. The effects of growing sorghum (*Sorghum bicolor*) in furrows and on the flat at three populations and three row widths in a semi-arid region of Zimbabwe. 1. Grain yield and yield components. *Zimbabwe Journal of Agricultural Research*, 31: 1-10.
- Nyamudeza, P. 1998. Water and fertility management for crop production in semi-arid Zimbabwe. Ph.D. Thesis. The University of Nottingham, UK.

- Oldrieve, B. 1993. Conservation farming for communal, small-scale, resettlement and cooperative farmers of Zimbabwe: a farm management handbook. Harare: Rio Tinto Foundation. 73pp.
- Oosterhout van, S.A.M. 1996. Copying strategies of smallholder farmers with adverse weather conditions regarding seed deployment of small grain crops during 1994/1995 cropping season in Zimbabwe. Volumes 1 to 3. SADC/GTZ, Harare.
- Osunbitan, J.A., Oyedele, D. J. and Adekalu, K.O. 2004. Tillage effects on bulky density, hydraulic conductivity and strength of a loamy sand soil in south western Nigeria. *Soil and Tillage Research*, 82: 57-64.
- Otegui, M.E., Andrade, F.H. and Suero, E.E. 1995. Growth, water use and kernel abortion of maize subjected to drought at silking. *Field Crops Research*, 40: 87-94.
- Otegui, M.E. and Bonhomme, R. 1998. Grain yields components in maize. I. Ear growth and kernel set. *Field Crops Research*, 56: 247-256.
- Pala, M, Buekes, D.J., Dimes, J.P. and Myers, R.J.K. 2005. Agronomic Management for Improved Water Use Efficiency in the Dry Areas of West Asia and North Africa. Proceedings of a Workshop organized by the Optimizing Soil Water Use Consortium, Ankara, Turkey. 22-26 April 2002. Aleppo, Syria: ICARDA; and Patancheru, India: ICRISAT. 288pp.
- Palm, C.A., Myers, R.J.K. and Nandwa, S.M. 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. pp193-217. In: Buresh, J.R., Sanchez, P.A. and Calhoun, F. (eds.). Replenishing soil fertility in Africa. Soil Science Society of America Special Publication Number 51.
- Pandey, R.K., Maranville, J.W. and Chetima, M.M. 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth, nitrogen uptake and water extraction. *Agriculture Water Management*, 46: 15-27.
- Peck, A.J. 1969. Entrapment, stability and persistence of air bubbles in soil water. *Australian Journal of Soil Science*, 7: 79-90.
- Petersen, P., Tardin, J.M. and Marochi, F. 1999. Participatory development of non-till systems without herbicide for family farming: The experience of the centre-

- south region of Parana. *Environment, Development and Sustainability*, 1: 235-252.
- Phillips, J.G., Cane, M.A. and Rosenzweig, C. 1998. ENSO, seasonal rainfall patterns and simulated maize yield variability in Zimbabwe. *Agricultural and Forest Meteorology*, 90: 39-50.
- Pilbeam, C.J., Tripathi, B.P., Sherchan, D.P., Gregory, P.J., and Gaunt, J. 2000. Nitrogen balances for households in the mid-hills of Nepal. *Agriculture, Ecosystems and Environment*, 79(1): 61-72.
- Plucknett, D.L. 1994. Sources of the next century's new technology. pp343-373. In: Anderson, J.R. (Ed.). *Agricultural Technology: Policy Issues for the International Community*. CAB International.
- Powell, J.M., Fernandez-Rivera, S., Hiernaux, P.A. and Turner, M.D. 1996. Nutrient cycling in integrated rangeland/crop land systems of the Sahel. *Agricultural Systems*, 52(2/3): 143-170.
- Reij, C., Scoones, I. and Toulmin, C. 1996. *Sustaining the Soil: Indigenous Soil and Water Conservation in Africa*. Earthscan Publications Ltd., London. 260pp.
- Rinaldi M., Losavio N. and Flagella Z. 2003. Evaluation and application of CROPGRO-soybean model for improving soybean management under rainfed conditions. *Agricultural Systems*, 78: 17-30.
- Rockström, J. and Rouw de, A. 1996. Water, nutrients and slope position in on-farm pearl millet cultivation in the Sahel. *Plant and Soil*, 195: 311-327.
- Rockström, J. Gordon, L., Folke, C., Falkenmark, M and Engwall, W. 1999. Linkages among water vapor flows, food production, and terrestrial ecosystem services. *Conservation Ecology* 3(2):5. <http://www.consecol.org/vol3/iss2/art5>
- Rockström, J. and Falkenmark, M. 2000. Critical reviews in plant sciences, 19(4): 319-346.
- Rockstrom, J. 2002. Potential of rainwater harvesting to reduce pressure on fresh water resources. *Dialogue on Water for Food and Environment*, International Water Conference, 14-16 October, Hanoi, Vietnam.

- Rockström, J., Barron, J. and Fox, P. 2002. Rainwater management for increased productivity among smallholder farmers in drought prone environments. *Physics and Chemistry of the Earth*, 27: 949-959.
- Rockström, J., Barron, J. and Fox, P. 2003. Water productivity in rainfed agriculture: Challenges and opportunities for smallholder farmers in drought prone agroecosystems. pp145-162. In: Kilne, J.W., Barker, R. and Molden, D. (eds.). *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. CAB International.
- Rosenzweig, C. 2001. Impacts of the El Nino-Southern Oscillation on agriculture: Guidelines for Regional Analysis. pp21-30. In: Hatfield, J.L., Volenec, J.J., Dick, W.A. and Kral, D.M. (eds.). *Impacts of El Niño and Climate Variability on Agriculture*. ASA Special Publication Number 63. 126pp.
- Rusike, J. and Heinrich, G.M. 2002. Integrated soil water and nutrient management farmer field schools in Zimbabwe. *Proceedings of a Review, Evaluation and Planning Workshop*, 11-12 December 2001, International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Bulawayo, Zimbabwe. 40pp.
- Qin R., Stamp P. and Richner W. 2006. Impact of tillage on maize rooting in a cambisol and luvisol in Switzerland. *Soil and Tillage Research*, 85: 50-61.
- Salinas-Garcia, J.R., Hons, F.M., Matocha, J.E., and Zuberer, D.A. 1997. Soil carbon and nitrogen dynamics as affected by long-term tillage and nitrogen fertilization. *Biology and Fertility of Soils*, 25: 182-188.
- Sasal, M. C., Andriulo, A. E. and Taboada, M. A. 2006. Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinean Pampas. *Soil and Tillage Research*, 87: 9-18.
- Sauer, T.J., Hatfield, J.L. and Prueger, J.H. 1996. Corn residue age and placement effects on evaporation and soil thermal regime. *Soil Science Society of America Journal*, 60: 1558-1564.
- Scoones, I and Cousins B. 1989. A participatory model for agricultural research and extension: The case of vleis, trees and grazing schemes in the dry south of Zimbabwe. *Zambezia*, 16: 45-65.

- SEDAP (South Eastern Dry Areas Project). 2001. Proceedings of a Workshop on Adaptive Research and Participatory Adaptive Trials held on 16-18 July 2001 at Montclair Hotel, Nyanga. Department of Research and Specialist Services. Zimbabwe.
- Shamudzarira, Z. and Robertson, M.J. 2002. Simulating the response of maize to nitrogen fertilizer in semi-arid Zimbabwe. *Experimental Agriculture*, 38:79-96.
- Shinde, S. S., Magar, S. S. and Kale, S. P. 1982. Effect of soil physical conditions and initial soil moisture content on infiltration into black soil. *Journal of Indian Society of Soil Science*, 30: 441-446.
- Shumba, E.M., Chisenga, M.M. and Ndebele, C. 1992. Contribution of fertilizer and management practices to the grain yield of maize in semi-arid areas of Zimbabwe. *Zimbabwe Journal of Agricultural Research*, 30(2): 137-143.
- Shumba, E.M., Waddington, S.R. and Rukuni, M. 1992. Use of tine tillage with atrazine weed control, to permit earlier planting of maize by smallholder farmers in Zimbabwe. *Experimental Agriculture*, 28:443-452.
- Sivakumar, M.V.K. 1992. Empirical analysis of dry spells for agricultural applications in West Africa. *Journal of Climate*, 5: 532-539.
- Sivakumar, M.V.K. and Salaam, S.A. 1999. Effect of year and fertilizer on water use efficiency of pearl millet (*Pennisetum sativum* L.) in Niger. *Journal of Agricultural Science*, 132:139-148.
- Smaling, E.M., Nandwa, S.M. and Janssen, B.H. 1997. Soil fertility in Africa is at stake. pp47-61. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F. (eds.). *Replenishing Soil Fertility in Africa*. Soil Science Society of America Special Publication N° 51.
- Smith, R.D. 1988. Tillage trials in Zimbabwe: 1957 to 1988. Consultancy report, November 1988. Institute of Agricultural Engineering (AGRITEX and GTZ), Harare.
- Smith, H.J. 2006. Development of a systems model facilitating action research with resource poor farmers for sustainable management of natural resources. Ph.D. Thesis. University of the Free State, Bloemfontein, South Africa. 297pp.

- Soil Science Society of America. 1986. Glossary of Soil Science Terms. Soil Science Society of America, Madison, Wisconsin.
- Sow, A.A., Hossner, L.R., Unger, P.W. and Stewart, B.A. 1997. Tillage and residue effects on root growth and yields of grain sorghum following wheat. *Soil and Tillage Research*, 44: 121-129.
- Sprent, J.I. 2007. Soil biology is an essential component of conservation agriculture, with particular reference to mycorrhiza and legume nodulation. pp103-110. In: Stewart, B.A., Asfary, A.F., Belloum, A., Steiner, K. and Friedrich, T. (eds.). *Proceedings of International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas*. 7-9 May 2007, Damascus, Syria.
- Steiner, K. 2007. Farmer participation in the development of conservation agriculture technologies. pp227-242. In: Stewart, B.A., Asfary, A.F., Belloum, A., Steiner, K. and Friedrich, T. (eds.). *Proceedings of International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas*. 7-9 May 2007, Damascus, Syria.
- Stern, R., Dennett, M.D. and Garbutt, D.J. 1981. The start of the rains in West Africa. *Journal of Climatology*, 1: 59-68.
- Stern, R., Dennett, M.D. and Dale, I.C. 1982. Analyzing daily rainfall measurements to give agronomically useful results. II. A modeling approach. *Experimental Agriculture*, 18: 237-253.
- Stern, R., Knock, J., Rijks, D. and Dale, I. 2003. *INSTAT Climatic Guide*. 398pp. <http://www.reading.ac.uk/ssc/software/instat/climatic.pdf>.
- Stocking, M. 1989. How Lesotho is tackling soil degradation. *Appropriate Technology*, 15: 14-16.
- Stocking, M.A. 2003. Tropical soils and food security: The next 50 years. *Science*, 302: 56-58.
- Tabor, J.H. 1995. Improving crop yields in the Sahel by means of water harvesting. *Journal of Arid Environments*, 30:83-106.
- Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, F. and Muchinda, M. 2007. Changes in growing-season rainfall

characteristics and downscaled scenarios of change over southern Africa: implications for growing maize. Regional expert meeting report. pp193-204. www.csag.uct.ac.za/~mtadross.

- Trenberth, K.E., Jones, P.D., Ambenje, P. Bojariu, R. Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. and Zhai, P. 2007. Observations: Surface and Atmospheric Climate Change. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 235pp.
- Tsimba, R., Hussein, J. and Ndlovu, L. R. 1999. Relationships between depth of tillage and soil physical characteristics of sites farmed by smallholders in Mutoko and Chinyika in Zimbabwe. <http://www.fao.org/ag/ags/agse/3ero/namibial/c111.htm>.
- Tsubo, M., Walker, S. and Hensley, M. 2005. Quantifying risk for water harvesting under semi-arid conditions. Part 1. Rainfall intensity generation. *Agricultural Water Management*, 76: 77-93.
- Twomlow, S.J. 1994. Field moisture characteristics of two fersiallitic soils in Zimbabwe. *Soil Use and Management*, 10: 168-173.
- Twomlow, S.J., Riches, C. and Mabasa, S. 1997. Weeding – Its contribution to soil water conservation in semi-arid maize production. Brighton Crop Protection Conference.
- Twomlow, S. J. and Bruneau, P.M.C. 1998. Soil-water regimes in semi-arid Zimbabwe. In: Wheeler, H and Kirby, C (Eds.). *Hydrology in Changing Environment. Proceedings of the British Hydrological Society International Conference*, Exeter, July, 1998. Vol. II. British Hydrological Society. John Wiley & Sons. Chichester.
- Twomlow, S.J. and Dhlwayo, H. 1999. Semi-arid maize yield responses to conservation tillage and weeding. Brighton Crop Protection Conference – Weeds, November 1999. Farnham, Surrey, UK :BCPC.

- Twomlow, S.J., Riches, C., O'Neill, D., Brookes, P. and Ellis-Jones, J. 1999. Sustainable dryland smallholder farming in sub-Saharan Africa. *Annals of Arid Zone*, 38 (2): 93-135.
- Twomlow, S.J. and Bruneau, P.M.C. 2000. The influence of tillage on semi-arid soil-water regimes in Zimbabwe. *Geoderma*, 95: 33-51.
- Twomlow, S. and Hove, L. 2006. Is conservation agriculture an option for vulnerable households? Briefing Note N° 4. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). September 2006.
- Twomlow, S. and Rohrbach, D. 2006. Achieving sustained gains in the food security of vulnerable households. Briefing Note N° 1. ICRISAT-Bulawayo. September 2006.
- Twomlow, S., Rohrbach, D., Rusike, J., Mupangwa, W., Dimes and Ncube, B. 2006a. Spreading the word on fertilizer in Zimbabwe. GlobalTheme on Agroecosystems Report N° 24. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Bulawayo. 11pp.
- Twomlow, S.J., Steyn, J.T., du Preez, C.C. 2006b. Dryland farming in southern Africa. Chapter 19. pp769-836. In: Petersen, G.A., Unger, W.P. and Payne, W.A. (eds.). *Dryland Agriculture 2nd Ed. Agronomy Monograph N° 23*. American Society of Agronomy, Madison, Wisconsin.
- Twomlow, S., Hove, L., Mupangwa, W., Masikati, P. and Mashingaidze, N. 2008a. Precision conservation agriculture for vulnerable farmers in low potential zones. Paper presented at the Challenge Program on Water and Food Theme 1 Rainfed Topic Workshop, 22-25 September, Tamale, Ghana.
- Twomlow, S., Rohrbach, D., Dimes, J., Rusike, J., Mupangwa, W., Ncube, B., Hove, L., Moyo, M., Mashingaidze, N. and Maphosa, P. 2008b. Micro-dosing as a pathway to Africa's Green Revolution: evidence from broad-scale on-farm trials. *Nutrient Cycling in Agroecosystems*, submitted.
- Twomlow, S.J., Urolov, J.C., Oldrieve, B. and Jenrich, M. 2008c. Lessons from the field – Zimbabwe's conservation agriculture taskforce. *Journal of SAT Agricultural Research* (in press).

- Unganai, L.S. 1990. Crop adaptability inventory for Zimbabwe: The edaphic and rainfall characteristics. Mimeo. Department of Meteorological Services, Harare, Zimbabwe.
- Unganai, S.L. 1996. Historic and future climatic changes in Zimbabwe. *Climate Research*, 6: 137-145.
- Unger, P.W. and Stewart, B.A. 1983. Soil management for water use efficiency: An Overview. pp419-454. In: Taylor, H.M., Jordan, W.R. and Sinclair, T.R. (eds.). *Limitations to Water Use in Crop Production*. Soil Science Society of America.
- UNDP. 2002. Preventing land degradation for sustaining livelihoods. Experience from GEF-UNDP projects, August 2002. http://www.undp.org/gef/undp-gef-publication/land_degradation_bronchure.pdf
- Van der Meer, F.W., 2000. Modelling tropical soil water regimes in semi-arid environments. Ph.D. Thesis, Loughborough University. 270pp.
- Vauchin, M. and Chopart, J.L. 1997. Multi-disc infiltrometry for *in-situ* determination of the surface hydrodynamic features of a gravel soil in Cote-d'Ivoire. *L'Agronomie Tropicale*, 46(4): 259-271.
- Verplancke, H. 1994. Water balance studies in the root zone of annual and perennial crops in rainfed and irrigated agriculture. Refresher Course for Alumni of the International Training Centre for Post-Graduate Soil Scientists of the Ghent University. *New Waves in Soil Science*. ITC-Ghent Publications Series N°5. BADC/University of Zimbabwe. Harare.
- Vincent, V. and Thomas, R.G. 1960. An Agricultural Survey of Southern Rhodesia (now Zimbabwe), Part 1. Agro-ecological Survey. Government Printers, Salisbury (now Harare).
- Vogel, H. 1992. Tillage effects on maize yield, rooting depth and soil water content on sandy soils in Zimbabwe. *Field Crops Research*, 33: 376-384.
- Waddington, S.R., Edmeades, G.O., Chapman, S.C. and Barreto, H.J. 1994. Where to with agricultural research for drought-prone maize environments? A Paper Presented at the Fourth Eastern and Southern Africa Regional Maize Conference, 28 March – 1 April 1994. Harare, Zimbabwe. 32pp.

- Willat, S.T. 1967. Moisture status of in Rhodesian soils prior to rains. Rhodesia Agricultural Journal, 64(1): 4-6.
- Woltering, L. 2005. Estimating the influence of on-farm conservation practices on the water balance: Case of the Mzinyathini catchment in Zimbabwe. M.Sc. Thesis. Delft University of Technology, The Netherlands, 103pp.
- Xiano-Bin, W., Dian-Xiong, C., Hoogmoed, W.B., Oenema, O. and Perdok, U.D. 2006. Potential effect of conservation tillage on sustainable land use: A review of global long-term studies. *Pedosphere*, 16(5): 587-595.
- Zaongo, C.G.L., Wendt, C.W., Lascano, R.J. and Juo, A.S.R. 1997. Interactions of water, mulch and nitrogen on sorghum in Niger. *Plant and Soil*, 197: 119-126.
- Zhai, R., Kachanoski, R.G. and Voroney, R.P. 1990. Tillage effects on spatial and temporal variations of soil water. *Soil Science Society of America Journal*, 54: 186-192.
- Zhang, R. 1997. Determination of soil sorptivity and hydraulic conductivity from the minidisk infiltrometer. *Soil Science Society of America Journal*, 61: 1024-1030.
- Zingore, S. 2006. Exploring diversity within smallholder farming systems in Zimbabwe: Nutrient use efficiencies and resource management strategies for crop production. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands. 258pp.

APPENDICES

Appendix 1. Guidelines for resource mapping and evaluation of tillage systems in Gwanda and Insiza districts

Resource Flow Mapping

- Draw homestead, the different fields and the kraals on-scale. First on the ground then on paper
- Indicate the soil type in each of the field
- Draw the different plots on each field and indicate what is grown on each plot or what was grown the previous year (depending on the time of year)
- How much seed was used for each plot?
- Was the seed retained or purchased?
- What is the amount of labour needed for the plots for ploughing, planting, weeding, etc. (in days and number of people working that day)?
- Who was involved in the different labour activities in each plot?
- Other inputs in the field: manure, fertiliser and pesticides?
- Yields of each plot: how many bags / kg / scotch carts (determine size) were yielded from each plot?
- Where did the grain go after harvest (draw arrow)
- Where did the stover go after harvest (draw arrow)

Focus Group Discussions

- Land preparation – when is it done for each tillage system? How long it takes?
- Application of soil fertility amendments – what amendments are used? How much is applied (scotchcarts/wheelbarrows? How are they applied? When applied? How often are amendments applied? How many people are involved in application of soil fertility amendments?
- Planting – When is it done for each tillage system? How is it done? How many people are required to do the operation?
- Crop establishment – which tillage system has best/poorest establishment --- in a

bad season and good season?

- Weeding – How is it done? How often is it carried out in below-normal, normal above-normal rainfall seasons? How long it takes per-unit area?
- Crop response to topdressing – leaf colour, plant vigour, yield?
- Pests/diseases attacks – Which pests/diseases are common in each tillage system? How severe is the attack? How often is the attack? What are the possible remedies?
- Rainwater harvesting – ranking of the tillage systems according to ability to harvest rainwater
- Waterlogging – in a season with above-normal rainfall
- Dry spell effect – which tillage system reduces the impact of dry spells on maize?
- Crop yield – in seasons with below-normal, normal and above-normal rainfall patterns?
- Technical support - which tillage system requires more support?
- Which organizations are providing technical support?

Appendix 2. Farmers who hosted on-farm experiments and participated in resource flow mapping and focus group discussions in Insiza and Gwanda districts

Name of farmer	District	Village
S. Mguni	Insiza	Masiyepambili
M. Mlalazi	Insiza	Thuthuka
M. Moyo	Insiza	Mpumelelo
M. Mpofu	Insiza	Mpumelelo
N. Ncube	Insiza	Mpumelelo
S. Nkomo	Insiza	Mpumelelo
M. Nyathi	Insiza	Mpumelelo
S. Nsingo	Insiza	Thuthuka
J. Dube	Gwanda	Mnyabetsi S
H. Magaya	Gwanda	Humbane
S. Malotha	Gwanda	Humbane
G. Mlilo	Gwanda	Magaya
K. Mlilo	Gwanda	Mnyabezi D
A. Moyo	Gwanda	Humbane
M. Nare	Gwanda	Mnyabetsi S
A. Ncube	Gwanda	Gohole
E. Ncube	Gwanda	Magaya
J. Ncube	Gwanda	Fumukwe
N. Sibanda	Gwanda	Mnyabezi D
T. Sibanda	Gwanda	Mnyabezi D
J. Siziba	Gwanda	Mnyabezi D
M. Siziba	Gwanda	Mnyabezi D
T. Tlou	Gwanda	Mnyabetsi S