SOIL WATER STATUS, MAIZE GROWTH AND YIELD UNDER TRADITIONAL FARMING PRACTICES AT BVUMBWE - MALAWI

BY

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ABSTRACT

An experiment was conducted at Bvumbwe Research Station in Malawi with the objective of characterizing the soil water status and maize (*Zea mays*) growth and yield under traditional tillage practices. Four tillage practices namely Open Ridge (OR), Residual Ridge (RR), Basin Ridge (BR) and Tie Ridge (TR) systems were used as treatments.

Instantaneous soil water content was determined *in situ* by using tensiometers (Model 2900F1) set in the field within 0 - 45 cm depth on rows, interrows, and 2/3 distance from interrows. Weekly gravimetric determinations of soil water at 0 - 45 cm depth were used to assess the profile soil water distribution characteristics at different maize development stages. Infiltration measurements soon after cultivation and after harvesting were determined by the double ring method. Runoff collection tanks were installed at the edge of each plot to collect runoff discharges from respective plots.

Plant performance was assessed on a complete randomised block design (CRBD). Treatment BR maintained the highest profile soil water content on rows, interrows and 2/3 distance from interrows during the greater part of the season, RR had the lowest whereas TR and OR had an intermediate profile soil water content. Row soil water readings were normally lower than interrows with a mean differrence of about 4.5 mm in OR and RR, 6.3 mm in BR and 5.4 mm in TR. The differential patterns of recharge and drying within the profile created spatial variations in soil water content at different depths. There was significant correlation between spatial variations and the mean soil water content. Subsurface recharge from interrows to rows, narrowed the spatial variations in soil water content in BR by about 0.0021 and a minimal rate of 0.00065 in RR.

Temporal variances in soil water content ranged from 0.0086 in BR and TR to 0.0053 in RR with intermediate temporal variance for OR treatment. The soil water behaviour showed a temporal dependence on spatial variations and a spatial dependence on temporal variations. Higher soil water content in BR was attributed to basin storage which promoted *in situ* water retention allowing longer periods for infiltration process to take place leading to the low runoff coefficient of 10% in BR, 18% in TR, 29% in OR and 47% in RR.

Maize performance was significantly related to the soil water content with the highest growth rate in BR treatment of 2.11 cm/day, TR 1.93 cm/day in TR, 1.84 cm/day in OR and 1.39 cm/day in RR at 59 DAP. Tasselling rate, leaf area Index, dry matter yield responded positively to the soil water variations in the treatments.

DECLARATION

I Kondwani Kenton Mwachilinda Kayira do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my own original work and that to the best of my knowledge it has not been submitted for a degree award in any other university.

Signature.. 23/10/96

Kondwani Kenton Mwachilinda Kayira

Date..

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DEDICATION

This dissertation is dedicated to my wife Jean and my daughters Sharon and Sandra for their love, understanding, encouragement and interest in my studies. I greatly appreciate their patience to let me travel to Tanzania at a time when they needed me most.

I also wish to dedicate this work to my father Kenton Kayira and his late brother Oswell Kayira (may his soul rest in peace) for their persistent encouragement and assistance to me personnaly and to my family during my absence. I wish Oswell lived longer to see the conclusion of his efforts.

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LIST OF SYMBOLS AND ABBREVIATIONS

a	constant of regression
b	constant of regression
BR	Basin Ridge/Tillage
CAgM	Commission of Agricultural Meteorology
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
D	Diffusivity
DD	Deep drainage
DAP	Days After Planting
DI	Dispersive Index
DMRT	Duncan's Multiple Range Test
Ei	Evaporation
ET	Evapotranspiration
FAO	Food and Agricultural Organisation
IFAD	International Fund for Agricultural Development
I	infiltration
If	Steady state infiltration rate
Ii	Initial infiltration rate
IITA	International Institute of Tropical Agriculture
k	Drying coefficient

K	Unsaturated hydraulic conductivity
Ks	Saturated hydraulic conductivity
kPa	kilopascal
L	Length of the soil column
LSD	Least Significant Difference
MORECS	Meteorological Office Rainfall and Evaporation Calculation Scheme
NPK	Nitrogen Phosphate & Potash
OR	Open Ridge
P	Precipitation
θ'	flux
Ro	Surface runoff
Ro/Rf	Runoff coefficient
RI_{30}	30 minute Maximum rainfall intensity
RI_{60}	60 minute maximum rainfall intensity
RR	Residual Ridge
s.e.	standard error
S_r	Total porosity
SWEAT	Soil Water Energy and Transpiration Model
SWC	Soil water conservation
SWD1+i	Soil water Depletion on day 1 location (i)
TR	Tie Ridge

CITATION

"By all account, plant life evolved in a watery medium followed by an invasion of dryland which forced plants to emancipate themselves, so to speak, to an environment in which water was no longer available in its original abundance" Meider 1983.

CHAPTER ONE

INTRODUCTION

Studies in environmental science in the twentieth century indicate a gradual decline in rainfall, possibly caused by the degeneration of climatic parameters through global warming and desertification (Hare, 1977; 1985). Ever since man cultivated crops in the ancient civilization along the Nile river in Egypt, Tigris and Euphrates rivers in Mesopotamia and the Yangtse Kiang river in China, water requirement for crop production has been recognised and considerable traditional innovations have been geared towards generating farming systems which are associated with water conservation.

A report of the Commission of Agricultural Meteorology (CAgM, 1982) estimated that about half of the world population is composed of subsistence farmers who practise traditional, labour intensive, rainfed agriculture. The traditional innovations in soil microclimate management which are being practised by small holder farmers have often been looked upon as primitive agricultural initiatives deleterious to the environment (Shaxson *et al.*, 1977). Studies on the effect of conventional tillage practices on soil water regimes have extensively been conducted and models to estimate the soil water profile characteristics have been proposed (Radke, 1982; Mahrer and Avissar, 1985; Gupta *et al.*, 1990). Since the Darcy - Richards soil water flow theory is grossly affected by the response of the physical and hydrological properties of the soil to tillage operations, it is anticipated that traditional land use systems should have a unique water status worth investigating.

In Malawi, about 90% of the agricultural land is under smallholder farmers who practise traditional farming systems with hand hoe and\or draught power. The traditional farmers apply knowledge and techniques of soil water management that have been acquired from individual, social experiences with locally available resources and ecological setting. Most of these local farmers do not have resources to buy tractors for tillage operations. The effort by the government to lease tractors to small holder farmers lasted only for two years (1978 - 1980) when funds from friendly donor nations were available to establish the small scale farmer tractor loan scheme (Singa, 1986). Just like many other soil and water management projects in Malawi and other developing countries, the life span of the projects are dictated upon by foreign investments and by adaptability to the small holder farmer. Once funding is withdrawn, the projects go to extinction as the small holder farmers cannot maintain such new and costly innovations. Therefore the focus of the current study was to build upon local resources which are responsive to the local conditions and adaptable to the constantly evolving physical and social conditions. Based on the same premise the research reported herein (Soil water regime and maize yield under traditional tillage practices) was geared to develop a menu of water management options to be recommended in regions with erratic rainfall distribution. Under such environments, crop production among small holder farmers who use traditional cultivation practices will principally be based on efficient utilisation of soil water. Therefore a knowledge of the frequency and magnitude of the recharge and drying cycles within the rainy season may help to indicate the most viable traditional land use practice for sustainable growth of maize in regions with erratic and unreliable rainfall.

The tillage practices studied in this project were open ridge, the residual ridge, the basin ridge or basin tillage or furrow diking and the tie ridge systems. These are traditional cultivation practices with minor modifications.

The general objective of this study was to characterise the soil water regime in open ridge, residual ridge, basin ridge and tie ridge systems of cultivation. Specifically the study aimed at the following:

(a) Evaluate the impact of traditional cultivation practices on soil physical properties.

(b) Evaluate the soil water status and depletion cycles in the different tillage systems during the cropping season.

(c) Evaluate the impact of traditional cultivation practices on infiltration process and runoff generation.

(d) Evaluate maize response to traditional tillage practices in terms of dry matter, plant height, leaf area index and grain yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Traditional cultivation practices.

Traditional agriculture is still being practised by a substantial percentage of farmers the world over. It has been estimated that about half of the world's population depends on subsistence (mainly traditional type of agriculture) and that 40% of the agricultural land of the world is in the hands of subsistence farmers (Commission of Agricultural Meteorology (CAgM). VII Report. 1982).

Traditional farming practices have evolved through centuries from shifting cultivation as practised by many communities in the developing countries. In Zambia. Zaire and Congo basin this system has popularly been referred to as 'chitemene system' (Fitzgerald. 1976) while in some parts of Malawi such as Nthalire and Misuku hills. it has been called 'kutema nthemere'. Despite limited research interests on traditional farming systems. indigenous cultural practices by small holder farmers have remained resilient to climatic vagaries associated with droughts and floods. leading to a minimum food security among small holder farmers (Msukwa. 1992). In recognition of this. the Commission of Agricultural Meteorology (CAgM) Advisory Working Group proposed that traditional microclimate management and manipulation systems be studied before changes in land use and/or agricultural management are proposed to smallholders by the extension service.

In an attempt to evaluate the potential of traditional farming systems in soil and water management, a conference on soil conservation was held in Addis Ababa in 1989 under the auspices of the centre for International Fund for Agricultural Development (IFAD) - Africa Division. The objective of the conference was to develop and integrate traditional farming systems into modern research (Reij, 1991). In that forum a farmer participatory approach was advocated as crucial to the development of sustainable traditional farming systems research. Policy statements were developed to challenge the present and future threats to land degradation by incorporating the small scale farmer's traditional know - how.

Okigbo (1977) and Ruthenberg (1980) state that indigenous African farming systems in their undisturbed form are ecologically sound and have evolved appropriate soil and water conservation techniques. But more often traditional land use practices have been condemned as being primitive initiative prone to land degradation and perpetual food insecurity among small holdings (Msukwa, 1992). Therefore, more research is required to enhance technical efficiency of traditional farming systems. This task calls for a multidisciplinary approach to cater for the social systems in which the farming practices emerged and the sustainability of the ecological balance.

2.2 Development of indigenous farming systems in Africa.

"Although many indigenous farming systems in Africa are now under severe pressure or are disintegrating into environmental abuse, they form the most viable basis for the development of a workable soil and water conservation (SWC) strategy for the future." (Reij *et al.*, 1986). In Malawi, as in many other developing countries in Africa, indigenous or traditional farming systems have been associated with underdevelopment and/or primitive agriculture. Hence little attention has been rendered to them in government research priorities. Despite the long historical background and widespread adoption of traditional agriculture among low resource farmers (constituting 75% of the population) in the country, there has been no significant attention from agronomists. Efforts directed to boosting water management in the traditional cotton growing regions of the Lower Shire were short lived between 1984 - 1986 (Panje, 1986). Prior to 1984 and after 1988, large sums of money were allocated to non traditional farming systems and ambitious conservation programmes which have often failed soon after the withdrawal of external funding (Amphlett 1982; Amphlett *et al.*, 1983). In many instances, high technological innovations which are very costly are more often not adapted by small scale farmers. Therefore, if government resources can be properly directed towards developing indigenous farming systems, a biological 'multiplier effect' in terms of crop productivity and soil and water conservation will be achieved. Examples of some of the indigenous farming systems associated with soil water conservation from Tunisia, Somalia, Sudan, Burkina Faso, Tanzania, Nigeria, Mali, and Malawi have been cited as follows:

2.2.1 Traditional farming systems in Tunisia.

In Tunisia, "tabias" and "jessours" are traditional water harvesting techniques within a stream bed. Tabias are earth dams 2 - 5 m high and extend up to 100 m long across the valley floors. Lateral spillways are constructed to control water flow and hold sediments upslope the tabias (Reij, 1991).

2.2.2 Traditional farming systems in Somalia

In Somalia the agropastoralists practise "caag" and "gawan" systems. The caag system is an innovation whereby the bund is used to capture overland flows from small gullies at a slope of 0.5%. The gawan system is an *in - situ* moisture conservation measure on plateaus. In this system contour bunds are constructed within the field to a height of 50 cm with a base width of 150 cm. Runoff water is controlled by providing gaps in the bunds which act as spillways (Reij, 1991).

2.2.3 Traditional farming systems in Sudan.

In Sudan, "teras" (which are earth bunds) are constructed on three sides of a cultivated land in which runoff is collected. Tied ridges have also been used in Sudan to impound rainfall (Reij, 1991).

2.2.4 Traditional farming systems in Burkina Faso.

The Dagari of Burkina Faso practised a rotational bush fallow system with some permanent cultivation. The prominent features of Soil Water Conservation include use of contour bunds on slopes, ridging along contour lines, use of a network of drainage ditches, the use of small and large mounds 3 - 9 m^2 with green manure worked under, alignment of stones around hill tops and fertilization of soil using green manure and cattle dung (Reij, 1991).

2.2.5 Traditional farming systems in Tanzania.

Similarly, the Matengo tribe in southern Tanzania dig circular or semi - circular pits which are locally called 'Ngoros' to a depth ranging between 30 to 45 cm and 100 to 150 cm in diameter. The purpose of the pits or basins is to increase storage of rainfall into surface depressions and hence reduce soil loss and storm runoff (Jones and Stewart, 1990). These pits are made across the furrow of the ridge - furrow tillage system. The pits retain rainfall on the surface until it infiltrates into the soil. The soil dug from the pit is used to bury crop residues and grass of the previous season. The current year furrows which constitute the pits become the ridges the following year. This system of cultivation acts as a water harvesting technique within a short runoff trajectory and hence can unequivocally be termed a microcatchment water harvesting technique (Ben - Asher and Boers, 1982). The raised ground surrounding the pits acts as a seed bed on which millet and sorghum are planted (Basehart, 1973).

Research by Jones and Stewart (1990) in the USA showed that plots with basins had low cumulative runoff and erosion compared to conventional tillage systems. However the efficiency of the basins declined with time and with storm intensity.

On the Ukara island - Tanzania, Ludwig (1968) reports of terracing, tied ridges and stone embarkments being used to conserve soil and water. Furthermore, the Nyiha tribe in Mbozi area practised shifting cultivation and fallowing. The main features included burning of turf and trees on the plot, use of mounds and ridges. Sorghum, finger millet and maize are the main crops grown in these areas. Finally, Dagg and Marcartney (1968) working on Oljoro region with calcareous clay, clay loam and sandy loam soils demonstrated the potential of tie ridges on runoff reduction. The trial also reports of a 40% yield increment on tied ridges compared to flat cultivation.

2.2.6 Traditional farming systems in Malawi.

A brief desription of the traditional cultivation practices in Malawi and elsewhere in the tropics is outlined as follows:

(1) **Use of ridges**

Ridging is a method of tillage in which the soil is dug up and concentrated in a defined region to deliberately raise the seedbed above the natural terrain (Lal, 1990). Ridge tillage in Malawi and in most of the tropical savannas has evolved as an integral component of traditional farming. The sequence of operations is simple and usually depends on manual labour. At the beginning of the cropping cycle, the natural vegetation is cut down and burned. This is followed by shallow cultivation with hoes (ridging) which normally aligns the row along the previous season's interrows. In other cases the previous seasons sod and weeds are buried in the ridge in order to improve the organic matter status and residual nutrient status of the soil (Jones, 1974; Benjamin *et al.*, 1990; Jones and Stewart 1990; Lal, 1990).

(ii) Tie ridges

The tie ridge system is an improved version of the traditional ridging. The ties are at a lower elevation (5 to 10 cm lower than the main ridge and connects two adjacent main ridges at right angles). A series of basins created by the ties hold surplus water and allow more time for it to infiltrate into the soil (Lawes, 1966; Dagg and Marcartney, 1968; Hulugalle, 1987; Day, 1988). Research conducted with tie ridges on upland alfisols in Sudan showed lower runoff collection; thus, 0 - 15% of the seasonal rainfall whilst 20 - 45% of the seasonal rainfall was collected on open ridges. The low runoff from tied ridges promoted high water use efficiency by the crop leading into higher crop yield (Hulugalle, 1987). Dagg and Macartney (1968) also reported significant increases in yields of cotton, sorghum and maize planted in tied ridges compared to those grown on flat surface in Sukumaland in Tanzania. Day (1988) reported an increase in infiltration (2 to 4 times) leading to higher food production (60-90%) on tied ridges than on flat cultivation on alfisols in Mali.

(iii) **Mound system of cultivation**

Mound or hillock system is a traditional seedbed preparation which has been used mainly by small holder low input subsistence farmers in the Congo basins (Lal, 1990) and in Malawi along the lakeshore area. Mounds are normally prepared by burying the sod with large amounts of earth. Mounds are generally big (about 3-4 metres in circumference) and in practice several planting stations of cassava are made on each mound.

(iv) **Flat cultivation**

Flat cultivation is the traditional method of seedbed preparation in Malawi. The grass and stover from the previous season crop are cleared and planting stations are made. This practice is often done for maize, sorghum and millet production in the lower Shire valley and in the northern region in Misuku and Nthalire in Chitipa District in Malawi.

Studies by El - Swaify *et al.* (1984) in India, have shown that performance of flat cultivation has been equal to other land surface configurations in terms of crop yield and have generally demonstrated superior control in soil and water losses from cropped field. In this respect, they advocated the use of ridges mainly in marginal areas with low rainfall. Similarly, higher yield has been reported on flat cultivation of sorghum in Sebele (Botswana) than on ridges (Land and Water Management Projects. 1988).

In all these traditional farming practices, there is minimal use of chemical fertilisers and the operations are labour intensive.

2.2.7 Research in soil water management in Malawi

In Malawi, trials aimed at developing improved soil and water management techniques have been conducted in the Lower Shire. The main objective of the studies was to achieve a sustainable crop productivity in the Makande vertisols which are characterized by high proportions of 2:1 clays, low permeability and low infiltration rate. Alternatively, studies have been conducted on the sandy rich soils classified as the Tomali series which are characterized as being highly friable and tend to form a crust due to rainfall impact (Panje, *et al.*, 1983). In these studies, conducted from 1974 to 1978, flat cultivation, open ridge system, tie ridge system and basin cultivation were tried and planted to sorghum and hybrid maize variety. High yields were obtained on basins but yields on tie ridge and flat slope cultivation were not significantly different.

Studies have also been conducted at Chitedze and Chitala Agricultural Research Stations to assess the effectiveness of tillage practices in crop growth and grain yield (Panje et al., 1986). In these studies, five treatments were used viz: Zero tillage, in which grass was killed by using herbicides (Lasso 72 ml/ha of 384 EC): Minimum tillage, in which the plot was ploughed once with a tractor and harrowed once and weed control was by use of herbicides (Lasso 72 ml/ha); Tractor cultivation; Ox ploughed plots and the last treatment was cultivation by using a hand hoe. A general fertilizer rate of 224 kg (NPK)/ha of 20:20:0 and a top dressing of 222 kg CAN/ha was applied. In these treatments, the highest yield was obtained in ox ploughed plots followed by hand hoed and tractor ploughed plots. The lowest yield was obtained in zero tillage due to pest and weed (Paspalum digitatum) infestation problem. The difference in yield was not statistically significant between treatments.

Further to the studies above, there have been experiments in Malawi to assess the effects of depth and time of ploughing in both fine textured and compacted soils on soil structure and maize yield. These studies were also aimed at assessing the suitability of soils in terms of trafficability and workability and timeliness in carrying out the right cultivation activity at the right soil water content. In these studies, treatments were zero tillage, shallow cultivation (0 - 15 cm) depth, deep cultivation (0 - 40 cm) depth done at the end of the previous rainy season when the soil was still moist and late tillage done just before the rains of the new season. In all the treatments, the yield of maize was lower in zero tillage on both early and late cultivation. Yields in the early deep ploughed plots were 5% higher than in late deep ploughed plots. Unlike the preceeding premise, the plots which were tilled late at shallow depth had higher yield than plots which were tilled early but with shallow depth of cultivation.

2.3 The effect of tillage on physical properties of the soil.

Tillage is generally the mechanical manipulation of the soil surface in order to modify soil conditions for crop establishment, growth and yield (Lal, 1982). In all tillage operations, a mechanical force which is applied to the soil tend to modify the state and behavioural properties of the soil. Tillage operations affect physical properties and hydrological properties of the soil through loosening the soil, compaction, crushing, shattering, shearing and inverting the soil (Lal, 1979, 1982; Adeoye, 1982; Cassel and Nelson, 1985; Kayombo, 1986; Griffith *et al.*, 1986; Benjamin *et al.*, 1990; Arora, *et al.*, 1990; Aina *et al.*, 1991; Cresswell *et al.*, 1991; Datiri and Lowery, 1991).

2.3.1 The effect of tillage on soil structure.

Griffith *et al.* (1986) studied the effects of different tillage operations on soil structure in Indiana, USA and found that after 5 years of maize (*Zea mays L)* cropping, the soil aggregate stability was increased in reduced tillage with the highest increases in the no till systems. Chisel and disc tillage systems produced aggregates with an intermediate level of stability. In the mouldboard tillage operation, most of the aggregates were pulverised. According to Griffith *et al.* (1986), yields of maize and soya beans *(Glycine max)* improved with time in no till plots and eventually exceeded those from the conventionally tilled soil.

Wyseure *et al.* (1992) demonstrated that tillage operations have immediate, short term and long term impact on physical properties of the soil. The gradual deterioration of soil structure, soil bulk density and total porosity due to mechanical force by tillage implements and rain drop impact during the rainy season have been stipulated in the structure degradation path analysis shown in Figure 1.

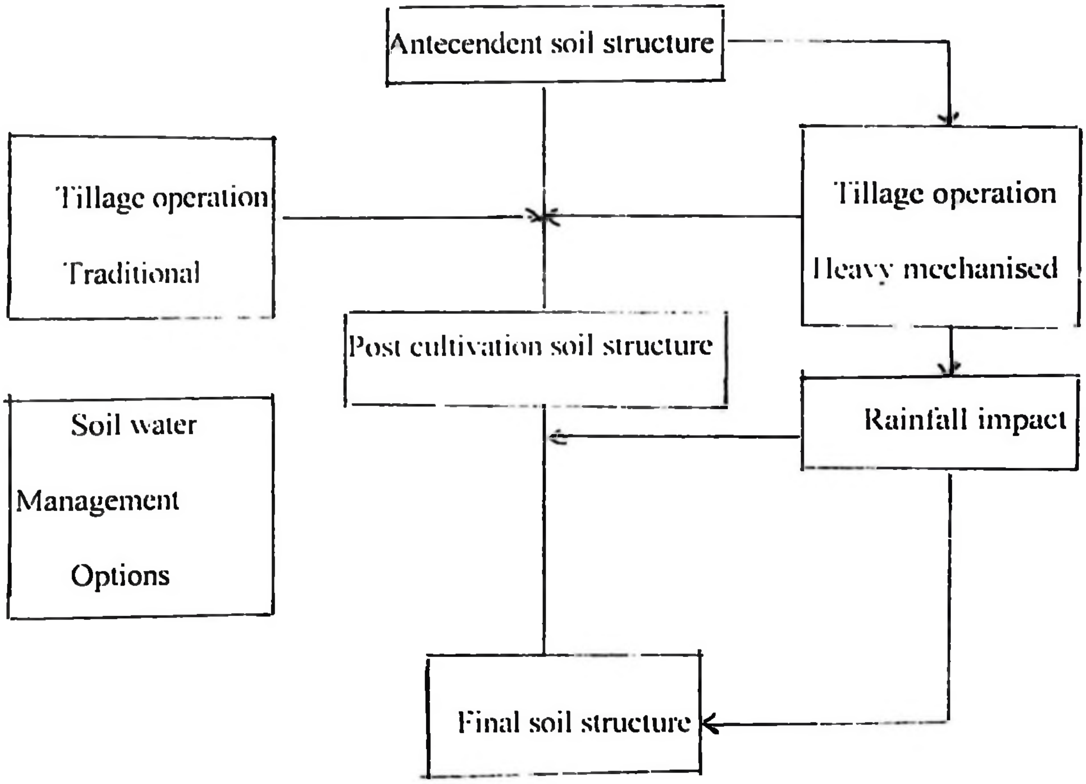


Figure. 1 The soil structure degradation pathway during cultivation.

(After Wyseure *et al.*, 1992).

2.3.2 The effect of tillage on bulk density of the soil

The effect of tillage on bulk density and mechanical impedance has been investigated by a number of scientists in recent years (Adeoye, 1982; Cresswell *et al.* 1991; Cassel and Nelson, 1985; Kayombo, 1986 and Agenbag and Maree, 1991). In all these studies, it was found that bulk density of the soil aggregates increased with depth depending on the degree of pressure exerted by different tillage systems. But also the studies showed that mechanized tillage systems cause spatial and temporal variations in soil texture, structure, pore size and pore size distribution and organic matter content. Cresswell *et al.* (1991) reported low bulk density values under minimum tillage while relatively higher bulk density values were recorded in the chisel, disk and mouldboard tillage. Studies conducted on alfisols on south west Nigeria showed that after five years of continuous mechanized farming using conventional tillage bulk density increased from 0.68 to 1.41 Mg/m^3 (IITA, 1984).

As opposed to traditional farming systems where light equipment is used in clearing the land, the continuous use of mechanized tillage systems on a piece of land exposes the structurally fragile soil to high intensity storms and year round high temperatures. These external forces tend to cause slumping of the soil due to excessive wetness and/or due to the kinetic energy associated with rainfall impact (Cassel, 1980). All these external forces tend to generate change in bulk density soon after tillage operations.

2.3.3 The effect of tillage on mechanical impedance of the soil.

Mechanical impedance is the capacity of the soil to withstand forces without experiencing failure whether by rupture, fragmentation and/or flow (Cassel, 1980; Adeoye, 1982; Kayombo, 1986 and Cresswell *et al.*, 1991). This parameter is evaluated by measuring the resistance to rupture by using a cone or pocket penetrometer (Cassel, 1980, Hillel, 1980). Research carried out by Cresswell *et al.* (1991) and Agenbag and Maree (1991) showed that cone resistance was lower for the tilled plots but rose significantly after the first rains when the pores were sealed with fine soil particles.

2.3.4 The effect of tillage on pore size distribution.

Tillage systems modify the size of the soil pore system and its continuity (Adeoye, 1982; Datiri and Lowery, 1991; Unger and Cassel, 1991). Pore size distribution is dynamic and depends on the ability of the soil aggregates to withstand pressure exerted by different tillage systems and rain drop impact (Adeoye, 1982). Unger and Cassel (1991) reported variations in pore size and pore size distribution between no till and conventional tillage. The no till plots had a smooth surface with small pores while fields cultivated with the mouldboard plough and disc plough created rough surfaces with large surface macropores which increased infiltration at the beginning of the rainy season.

2.4 The effect of tillage on the hydrological properties of the soil.

2.4.1 Simulation of cropland soil water balance

Computer simulation models to describe soil water recharge and depletion patterns have been developed by crop modelling experts based on the simplified continuity equation of the soil - plant - atmosphere - continuum (Phillip. 1966). The continuity equation which constitutes the law of conservation of matter and energy in an ecological system can be represented as follows (Hillel. 1979. 1980):

$$\theta p = (P + I) - (R - ET - DD) \qquad (1)$$

where θp is profile soil water content. P is precipitation (which could be rainfall. irrigation. dew and frost). R is runoff. ET is evapotranspiration and DD is deep drainage below the root zone and I is infiltration.

Campbell (1974) advocated the use of MORECS (Meteorological Office Rainfall and Evaporation Calculation Scheme) in order to estimate weekly and monthly evapotranspiration. soil water depletion pattern and other components of the water balance. The MORECS soil water depletion term derived from equation (1) is

$$SWD_{i+1} = SWD_i + E_i - P_i \quad \text{for } SWD > 0 \qquad (2)$$

$$SWD_{i+1} = E_i - P_i \quad \text{for } SWD < 0 \qquad (3)$$

where SWD_i is soil water depletion on day (i). E_i is evaporation on day (i) SWD_{i+1} is soil water predicted by the model for day (I+1).

Similarly, Campbell (1985), Bristow *et al.* (1986) and Choudhury and Monteith (1988) used the Soil Water Energy and Tanspiration (SWEAT) model to estimate soil water and other components in the continuity equation. Both MORECS and SWEAT, however, do not describe the spatial variability of soil water under different soil management practices. Lack of flexibility in the models to accommodate the variations in rainfall intensity and subsequent distortions in the infiltration and runoff relationship with time, limits the use and adaptability of these models.

2.4.2 The effect of tillage practices on soil water retention

Conservation tillage systems generally have higher soil water content during a large part of the growing season due to increased infiltration and decreased evaporation losses. Research by Blevins *et al.* (1983), Adeoye (1982), Johnstone *et al.* (1984), Griffith *et al.* (1986), Benjamin *et al.* (1990), Agenbag and Maree (1991), and by Arora *et al.* (1991), has shown that soil volumetric water content is higher in reduced tillage than in the conventional mouldboard and discing systems. Likewise, studies conducted by Osuji (1984) in Northern Nigeria showed higher water content in manual tillage systems within 0 - 30 cm depth than in the mechanized farming system. But beyond 30 cm depth tillage operations seemed not to have significant influence on the soil water regime.

Zhai *et al.* (1990) studied soil water retention by evaluating the recharge and drying coefficients of a Typic Hapludalf (Loam) soil subjected to conventional tillage practices (CT), short term no tillage (SNT) system and long term no tillage (LNT) systems. Spatial and temporal variations in soil water content were determined by using permanently placed time domain reflectometry (TDR) transmission line probes (Van Wesenbeech and Kachanoski, 1988; Van Wesenbeech *et al.*, 1988). The drying and recharge coefficients on row, interrows and 1/4 point from the interrows were evaluated by the following relationship:

$$\theta_{it} = \theta_{io} \exp(-k_i t) \qquad (4)$$

where θ_{it} is soil water content at different layers at location i; t is duration between subsequent measurements, θ_{io} is soil water content at the start of the drying phase after a recharge effect; k_i is the drying rate constant (per day) at location i.

In this study the long term no tillage treatment had a better water conservation on rows and interrows than conventional tillage practices at all stages of crop growth. This was associated with the low drying coefficients in LNT and SNT compared to CT.

2.4.3 The effect of tillage on infiltration rate

2.4.3.1 Empirical infiltration models

Horton (1940) defined infiltration as entry of water into a soil profile from the surface with maximum infiltration capacity reached when a steady state flux movement is realised. Childs (1969) considers infiltration process as flux movement into the profile as a function of hydraulic conductivity and hydraulic gradient at the soil surface. The latter definition takes account of the transient water flow patterns which are incorporated in the Richard's one dimensional equation as follows:

$$\delta\theta/\delta t = \delta/\delta z\,[K(h)(\delta h/\delta z) + 1] \qquad (5)$$

where $d\theta/\delta t$ is change in profile water content upon infiltration. K is hydraulic conductivity of the surface layer and of the bulk of the whole profile. h is depth of the surface layer. $\delta h/\delta z$ is the hydraulic gradient.

By adopting this model, several scientists have demonstrated the infiltration processes by using simulated rainfall on small 1m x 1m experimental plots (Burwell and Larson, 1969; Swartzendruber, 1960; Sidira *et al.*, 1983; Morin *et al.*, 1984; Burch *et al.*, 1986). The limitation of a small watershed simulation experiment is lack of true replicability on rainfall distribution and intensity and their effect on infiltration model. But also, lack of authentic representation of field management systems and cultural practices limit the adoption of simulation experiments for large catchments. In view of this shortcoming in most models, a relationship to predict the infiltration rate for a bare soil was proposed by Morin *et al.* (1984) as follows:

$$I = If + (Ii - If) \exp(-\gamma pt) \qquad (6)$$

where Ii and If are the initial and final (steady state) infiltration rates respectively; t is time from the beginning of the rain, γ is the soil coefficient related to soil stability and p is the rainfall intensity.

2.4.4 The effect of tillage practices on Infiltration and surface runoff.

Rockwood and Lal (1984) carried out research on the effect of tillage on surface runoff and infiltration rate on a plot planted with maize in Nigeria. Runoff collection from bare fallow plots was higher than runoff collected from ploughed plots. The reduction of runoff in ploughed plots was due to ponding on the depressions which allowed more time for water to infiltrate into the soil.

Similar studies were conducted by Nicou *et al.* (1986) in Burkina Faso with the aim of determining the effect of tine tillage, ploughing, ridging and tied ridging on the water balance and yield of crops. Over the three years that the experiment was conducted, ploughed plots had low runoff values especially at the beginning of the rainy season. Ridging and tied ridges promoted infiltration which sustained higher moisture content throughout the growing season and even when drought conditions prevailed.

Van de Weert and Lenselink (1972), cited by Kayombo (1986), reports that mechanical clearing of land in Surinam resulted into a large reduction of infiltration rate and a total elimination of macroporosity to soil depth of up to 25 cm. Likewise, Alegre *et al.* (1982), cited by Kayombo (1986), demonstrated in a research carried out in Peru that the manually cleared plots had higher infiltration rates averaging 10 cm/h whilst the plots cleared by bulldozers or tractor drawn implements induced compaction which reduced the infiltration rate to 0.5 cm/h. Studies conducted in Nigeria by Lal and Cumming (1979) showed that soil cleared by mechanical and heavy duty tools decreased infiltration rate, total porosity and the proportion of macropores (>14.3 mm radius) through compaction of the soil by tyre pressure and/or heavy duty tillage implements.

2.4.5 The effect of tillage practices on hydraulic conductivity.

Datiri and Lowery (1991) carried out studies on the infiltration rates and hydraulic conductivities of the Gilstone silt loam soils. The studies showed that the hydraulic conductivity is greatly influenced by the nature and arrangement of pores. When water infiltrates into a dry soil, fine pores are filled first and transmit water first followed by larger pores at or near saturation point (Hillel, 1979, 1980; Datiri and Lowery, 1991). It was concluded, therefore, that the hydraulic conductivity of the soil depends on porosity, initial moisture of the soil and the heterogeneity of the soil.

Studies by Morin *et al.* (1984) on soils which develop surface crusts upon impact by raindrops showed that hydraulic conductivity tends to decrease with time. The conductivity of the crust layer was estimated by using the equation:

$$K_c = K_f + (K_i - K_f) - \exp(\gamma p t) \qquad (7)$$

where Kc is conductivity of the crusted layer (cm/h). K_f is final hydraulic conductivity (cm/h). K_i is initial hydraulic conductivity.

2.4.6 The effect of tillage on soil temperature and heat flux.

Griffith *et al.* (1986) and Benjamin *et al.* (1990) observed that maximum and daily average soil temperatures were lower under conservation tillage than under conventional mouldboard tillage especially in the first 4 to 6 weeks after planting. The lower soil temperatures were caused by the higher residue cover and higher soil water content. The temperature differences play a significant role in the transmission of water under unsaturated conditions (Hillel, 1980; Benjamin *et al.*, 1990).

Research conducted by Benjamin *et al.* (1990) on water and heat transport on flat, furrows or ridge treatments showed higher maximum temperature and lower minimum temperature on ridge than on flat surface or on furrows. Hence, the ridge peak dried more quickly than the furrow. Similarly, Gupta *et al.* (1990) found a sinusoidal temperature pattern between a ridge and furrow system. Whilst on a similar study, Hulugalle (1987) found no significant soil temperature difference between flat cultivation and open ridging.

2.5 The effect of tillage on crop production.

2.5.1 Plant growth and grain yield

Long term tillage studies were conducted throughout the state of Indiana to measure crop growth and yield under different tillage systems. The results indicated that conservation tillage produced higher maize yields than the yields from the conventional mouldboard tillage. The studies showed that reduced tillage gave higher dry matter yield, fast growth rate and high grain yield on well drained or sloping soils than on poorly drained soils (Griffith *et al.*, 1986). Studies conducted in semi arid parts of Tanzania by Dagg and Marcartney (1968) comply with the results obtained by Griffith *et al.* (1986). But also Osuji (1984), working on tropical alfisols in Nigeria, showed that mechanically cultivated plots had higher yield advantage over the manually tilled plots in the early phases of the experiment. However, the long term effect of manually cultivated land resulted into an equally or relatively higher crop production than the mechanically tilled plots.

2.5.2 Root growth and distribution

Tillage effects have an impact on root growth and development through soil compaction (Kayombo, 1986). According to Arora *et al.* (1990) root length index (RLI) [which is a depth integral of root length in a given segment of rooted profile] in disc or mouldboard tilled plots was almost double that of reduced tillage and/or shallow tilled soils. In conventional tillage practices, the soil loosening process promotes good root proliferation as opposed to shallow cultivation methods.

2.5.3 Water requirement by plants

Water constitutes more than 90% of the fresh weight in most plants (Turner and Burch, 1983). Soil water status is dependent on soil management practices, soil type and crop factors. When soil water reserve is depleted plants have to expend more energy to counteract the matric forces which hold water to the soil colloids (Veehmeyer and Hendrickson, 1950). The droughts occurring intermittently within the rainfall season tend to have adverse effects on the physiological and morphological processes in plants (Turner and Burch, 1983) and have been reported by many agronomists to considerably affect both grain and dry matter yield.

2.5.4 Critical water demand periods by maize

Robin and Domingo (1983) reported that wilting of only 1 to 2 days during pollination period reduced maize yield by 22%. A stress of 6 to 8 days reduced yield by 50%.

Denmead and Shaw (1960) reported about 50% reduction in maize yield in pot experiment stressed for 5 days within the tasselling and silking stages. Similar stress conditions prevailing at ear development and senescence stages gave 25% and 21% reduction in yield respectively.

Studies by Claassen and Shaw (1970a,b) report of plants subjected to various irrigation programmes. In these studies, stresses of up to 4 days rendered significant effect on crop vegetative growth. Dry matter and grain yield dropped by about 15% and 17% respectively when crop was stressed for three weeks during tasselling period. Yield reduction of more than 50% was reported for events where drought conditions persisted at 75% tasselling stage.

In all these studies water stress at silking stage was more critical to grain yield than stress at other phenological stages.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of experimental site

The experiment was conducted at Bvumbwe Research Station in Malawi. The basement complex is basically composed of Precambrian charnokitic granulite intergrade with gnessic banding (Geology Map of Malawi, 1979).

3.1.1 Climate

The agroclimate is influenced and modified by the great diversity in physiograghy. The experimental site is located in the intergrade between the rift valley floor and the rift valley escarpment. The impact of the Semi Arid condition of the Lower Shire Valley, classified as Sahelo Sudanese (UNDP, 1970), has in the past 5 years (1989-1994) generated a wave of dry weather which has grossly affected the rainfall pattern in the area. The winters are cool from May to August with lowest annual temperatures of 10^0c in July and annual maximum temperatures of 32^0c in October. The occurrence of rainfall in Summer, normally from October to April, is a result of the interaction between the sub tropical ridge of high pressure and the Equatorial low pressure belt or the Inter Tropical Convergence Zone (ITCZ). When the Equatorial trough moves south in Summer, the collision with North East Monsoon Winds bring moist air which gives rise to convectional rainfall - typical of the area up to the Lower Shire and the Thyolo escarpment which overruns the experimental site.. Spatial and temporal variations in rainfall distribution in the region is quite significant partly due to variation in physiography and partly due to air pressure inversion created by the adiabatic cooling of the rising warm air pockets.

Mean annual rainfall range from 600 - 1200 mm as shown in Fig.ure 2 . Sometimes. however. rainfall of higher intensity is recorded when cyclones originating in the Indian Ocean cross the Mozambique channel into the mainland.

The UNDP (1970) subjected ten years of rainfall figures from 46 recording stations in the region to statistical analysis The data showed low probability values on rainfall occurrence on a 10 day period and a high coefficient of variation in rainfall distribution. Assessment of 40 years rainfall records reveal cases of below normal or excessive annual rainfall causing significant runoff as shown on Figure 3.

3.1.2 Vegetation

The vegetation in this area is characteristic broad leaved tall *Brachystegia spp.* Despite heavy deforestation for arable cropping, remnants of *Brachystegia julbernardia* and

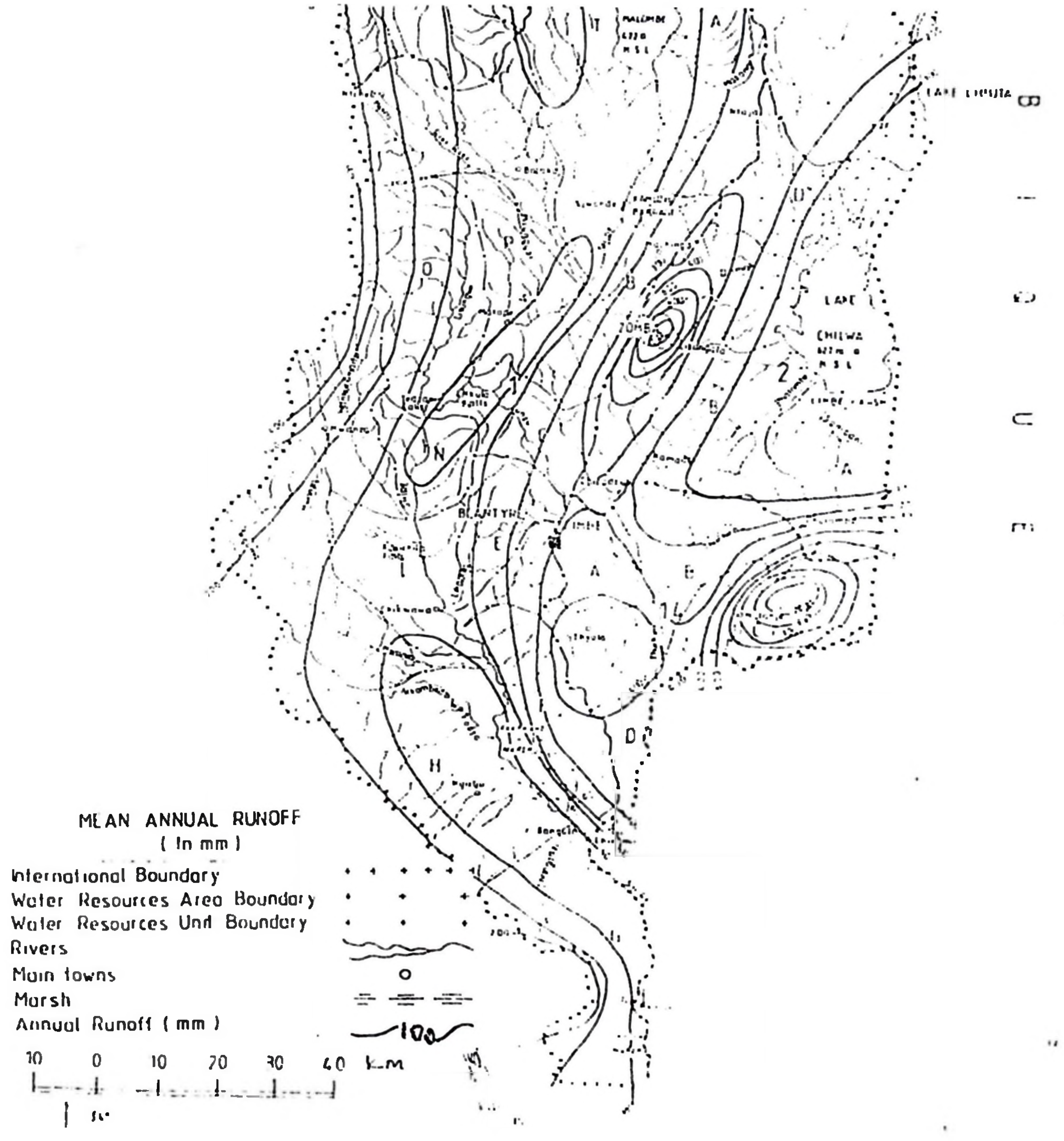


Figure 2. Annual mean rainfall distribution in the Southern region of Malawi

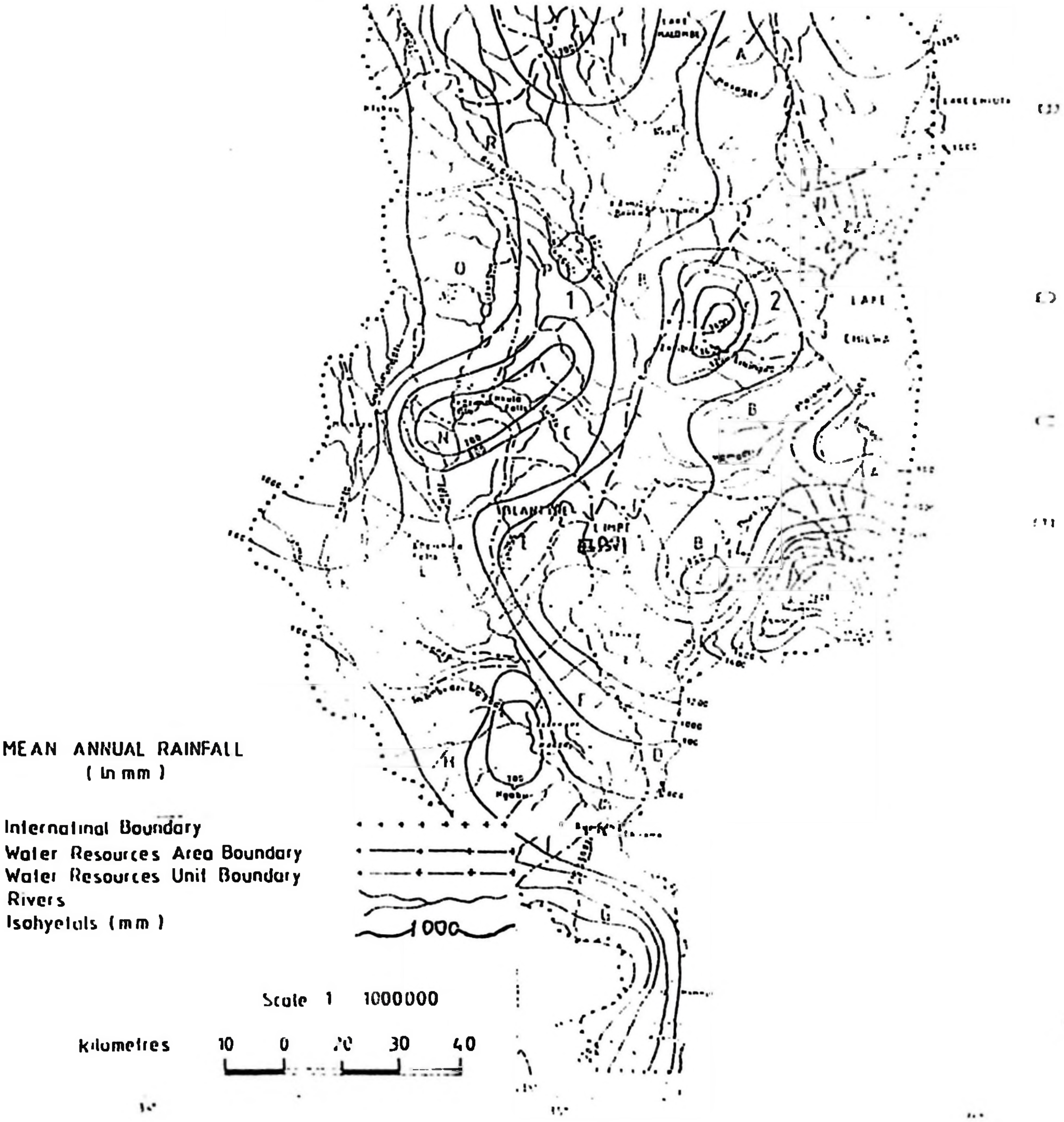


Figure 3 Annual mean runoff discharges (mm)

Brachystegia isoberlinia (Stobbs, 1970 and Shaxson, 1977) can be seen here and there. During the dry season, tall grass grows giving typical Savanna biotic communities.

3.2 Soil characterization.

A preliminary survey of the site was done. A total of 12 small profiles 0 - 90 cm depth in which runoff collection drums were installed, were studied (See Figure 4). Besides these, one profile was extended to 200 cm depth at a site adjacent to the experimental site and soil horizons were described according to the soil taxonomy and USDA systems as indicated in Appendix 1a. Soil samples collected from the profile at 0 - 15, 15 - 28, 28 - 76, 76- 115, 115 - 145, 145 - 160, 160 - 200 cm were used for textural and chemical analysis as follows:

3.2.1 Particle size analysis.

This was done by using the hydrometer method as modified by Anderson and Ingram (1993). The density of the soil water suspension was measured with a Bouyocous hydrometer which was calibrated to read the density of the soil water suspension in grams per litre (g/litre) for a given time and temperature. The dispersing agent used in the sedimentation cylinder was sodium hexametaphosphate and the suspension was made up to the one litre mark with distilled water. The hydrometer readings were corrected for the temperature changes and the proportion of suspended material (sand, silt and clay) were calculated as the percentage of the ratio of the hydrometer reading and the oven dry weight of the soil. The textural classes presented in Table 1 were defined based on the USDA textural triangular.

Table 1. Particle size distribution before tillage operation.

Depth(cm)	%Silt	%clay	%sand	class
0-15	10	33	57	scl
15-28	9	35	56	scl/sc
28-76	8	55	37	c
76-115	4	69	27	c
115-145	7	51	42	c
145-160	7	53	42	c
160-200	8	53	39	c

scl - sandy clay loam
sc - sandy clay
c - clay

Lowole and Chilima. (personal communication) classified the experimental site as a Typic Thermic Hapludalf based on the USDA (1975). The soil is classified as follows:

Order : Alfisol

Sub order : Udalf

Great groups: Hapludalf

Subgroup : Typic Hapludalf

Families : Kaolinite Typic Thermic Hapludalf

3.2.2 Chemical analysis

Soil acidity was determined by measuring the pH of 1:10 soil : solution suspension using a CD 620 digital pH meter. Total nitrogen content was determined by the kjeldahl method (Bremner.1965).

Extractable Phosphorus was determined by the Bray and Kurtz (1945) method. This method removes Phosphorous by dissolution of the sorbing components and extracting some sorbed Phosphorous by desorption. A modified procedure which uses 14 cm^3 solution containing 0.03M NH_4F and 0.025M HCl with 2g of soil was adopted. The extractable P was determined colorimetrically by the ascorbic acid method of Olsen *et al.* (1954).

Organic carbon was determined by the dry combustion method with potassium dichromate as stated by Allison (1965) and modified by Anderson and Ingram (1993).

The exchangeable bases were extracted from the soil with 1M CH_3COONH_4, pH 7.0 and using 1M KCl for comparison. Ca and Mg were measured using a Perkin - Elmer model

3030 atomic absorption spectrophotometer (AAS) with air acetylene flame at 422.7 nm and 285.2 nm wavelengths respectively. Potasium was estimated by a flame photometer.

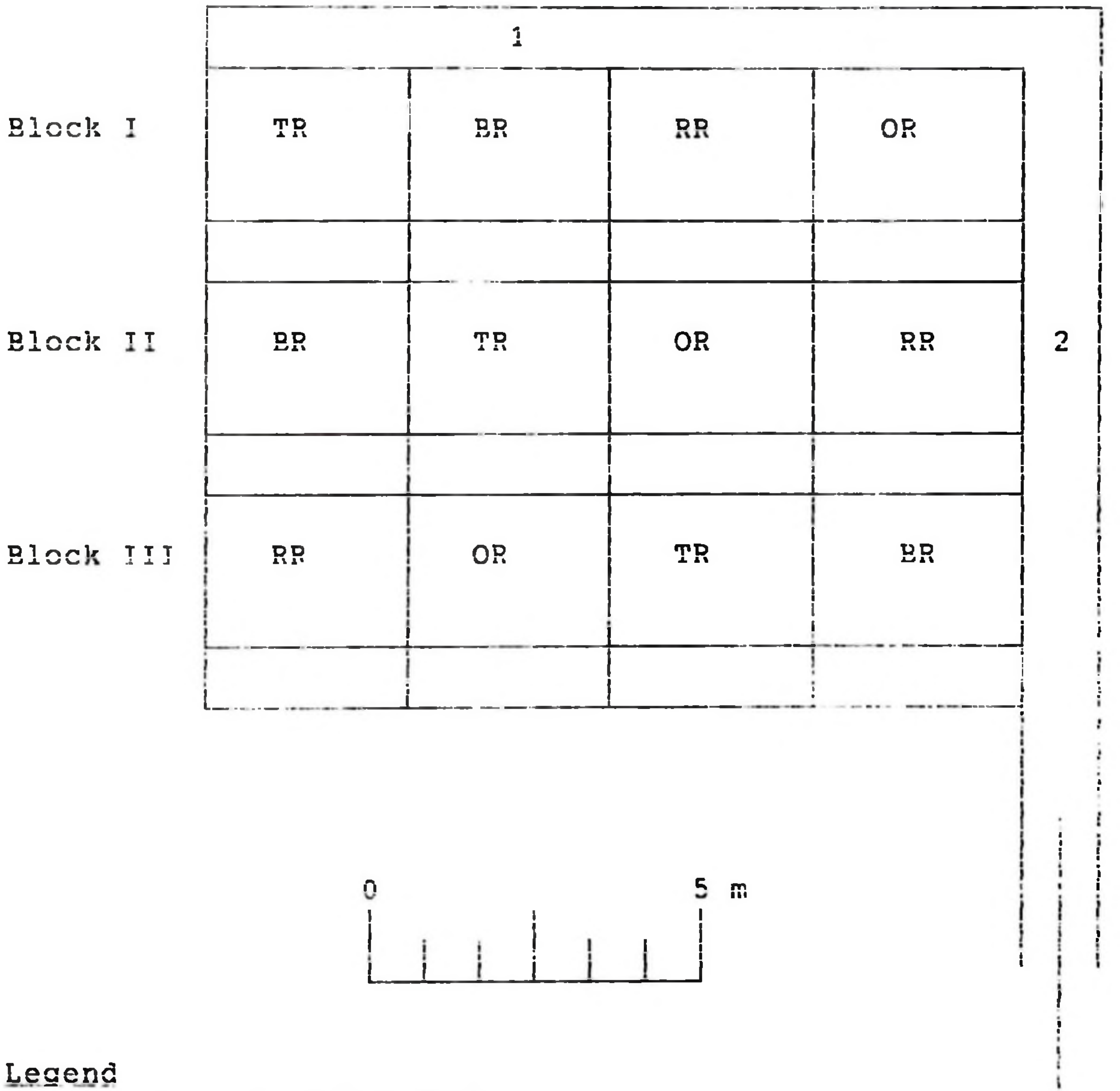
Micronutrients i.e. Cu. Zn. Mn and Fe were determined by extracting with DTPA (Diethylenetriamine penta acetate at pH 7.3. The concentrations of Cu. Zn and Fe were measured using the Perkin Elmer Model 3030 AAS. All the chemical properties of the Kaolinite Typic Thermic Hapludalf soil are reported in Appendix 1b.

3.3 Experimental layout

Each plot was 5.4 x 5.4 m with a runoff discharge channel 5.4 m x 0.6 m running parallel to the experimental plots. A storm drain (22 x 1 x 0.45m) was made on the upper part of the field. A waterway was constructed to lead the runoff discharge from the storm drain to a safe disposal area as shown in Figure 4. The experimental site was flat with a slope of 0.02%.

3.3.1 Treatments and experimental design.

A randomised complete block design (RCBD) with 4 tillage treatments replicated three times was used. The treatments namely, open ridge, basin ridge, tie ridge and residual ridges, were prepared just before the rains with ridges spaced at 90 cm apart.



Legend
O = Runoff collection tank
1 = Storm drain
2 = Water way

BR = Basin ridge / Tillage
TR = Tie ridge
RR = Residual ridge
OR = Open ridge

Figure 4. The experimental layout.

(i) **Open ridge system (OR)**

This is a traditional cultivation in which the ridge is made in the furrows of the previous ridges. The previous crop residues were cleared but a good soil depth was made to act as seedbed. The height of the ridge measured from the centre of the furrow was 30 cm.

(ii) **Residual ridge system (RR).**

In this case the previous ridges were used as seedbed for the crop. The previous vegetation was just burnt and the seedbed was prepared by making planting stations and removing the unburnt stalks using a handhoe without further disturbing the ridges. The average height of residual ridges was 10 cm.

(iii) **Basin ridge system (BR).**

Ridges were made just like in OR with furrows divided into 4 basins spaced 100 cm apart. Basins were sunk 45 cm below the ridge height. The soil removed from the basins was used to raise the wall of the basins which connects the two parallel ridges at right angles. The basins were U - shaped.

(iv) **Tie ridge system (TR).**

This is an open ridge with ties made at a spacing of 150 cm apart. The height of the ties was 10 cm below the main ridge and cut the main ridge at a right angle.

Likewise, the previous season furrows become the position of the current sesason rows.

In all treatments, runoff collection tanks were installed at the edge of each plot as indicated on Figure 4. The tanks were set within the channel making a boundary between the blocks. An early maturing hybrid maize NSCM 41 variety was planted on November 14, 1993 at 4 seeds per station spaced 90 cm apart. The total number of seeds per plot was 120 and were thinned to 3 plants per station giving a total plant population of 37,000 plants/hectare. Single application of 23:23:0 NPK was done two weeks after emergency at 224 kg NPK/ha emulating the low chemical nutrient input by small holder farmers.

3.3.2 Statistical analysis

Simple correlation coefficients were calculated between mean soil water content and the spatial and temporal variances in soil water content between treatments. Analysis of variance (ANOVA) as outlined by Snedecor and Cochran (1989) was used to assess treatment effect on physical, hydrological and crop parameters based on the model:

$$Y_{ij} = \mu + T_i + \beta_j + \varepsilon_{ij} \qquad (8)$$

where Y_{ij} = response, μ is general mean (residual moisture content), T_i is treatment effect, β_j is block effect, ε_{ij} is error effect. Treatment means were compared by using the Duncan's New Multiple Range Test.

3.4 Agrometeorological data.

Agrometeorological parameters (appendix 2a) were observed from the meteorological station located 100 metres from the experimental field. Hence those observations made at the station were assumed to apply to the experimental site. The following meteorological parameters were determined:

Maximum and minimum temperature and the dry bulb depression were measured by the maximum and minimum thermometers and the dry and wet bulb thermometers respectively; Rainfall was measured by the autographic rainfall recorder and the tipping bucket type gauge. Rainfall data was subjected to pentade analysis (see appendix 2b) in which 5 day averages were plotted against the number of pentades in the season. Rainfall intensities were calculated from the autographic rainfall charts and 30 minute maximum intensity (RI_{30}) and 60 minutes maximum rainfall intensity (RI_{60}) were calculated. The number of rainy days were also calculated from the daily rainfall records for each month. The rainy days were considered as days receiving more than 0.5 mm. Likewise the length of dry spells was calculated as days receiving equal and or less than 0.5 mm.

Sunshine duration was measured by using the Campbell Stokes sunshine recorder. Wind speed was measured by using the cup anemometer installed 2 metres above the ground. Pan evaporation was measured by using a US class A pan which was 1220 mm in diameter. The data was collected for the period from 1st October 1993 to 31st April 1994.

3.5 Determination of physical properties of the soil after tillage operations

3.5.1 Dry bulk density

Samples for bulk density determination were collected from each treatment using a core sampler with removable cylinders that fit into the main core sampler. This was done two days after the first rains in order to minimise compaction. The initial bulk density (ρb) determination was sampled from the following depth viz: 0 - 5, 15 - 20, 40 -45, 60 - 65, 100 - 105, 145 - 150 cm depth in order to characterize the soil. Subsequent ρb determinations were sampled from 0 - 5, 10 - 15, 25 - 30, 40 - 45 cm depth after every 4 weeks. Excess soil on the core was scrapped off using a sharp knife so that the soil was levelled with the core. The core samples were weighed and then dried for 48 hours at 105^{0}C. The dry bulk density was calculated by dividing the mass of the oven dried soil by the core volume (Blake and Hartge 1986).

3.5.2 Total porosity and % macroporosity

Total porosity of the soil is the volume of voids in a core sample. This was calculated from the relationship of bulk density (ρ_b) and particle density (ρ_p) as follows:

$$S_t = (1-\rho_b/\rho_p) \qquad (9a)$$

where S_t is total porosity (%), ρ_b is bulk density (Mg/m^3), ρ_p is particle density assumed ρ_p = 2.65 Mg/m^3 for most mineral soil (Blake and Hartge, 1986; Saka and Haque, 1993).

Macroporosity is the void proportion which drains first after the rains and constitutes the largest pore size fraction in the core soil sample. The proportion of macropores is defined by finding the difference between total porosity and soil water content at field capacity as follows:

$$\text{Macroporosity} = S_t - \theta_{V(FC)} \qquad (9b)$$

where S_t is the total porosity and $\theta_{V(FC)}$ is the volumetric water content at field capacity.

3.5.3 Aggregate stability

3.5.3.1 Dry Sieving Method.

Air dried 10g soil samples were sieved on a 0.2 mm sieve. The samples were agitated by shaking the sieve by hand until all fine material passed through the sieve. The degree of aggregation was calculated as indicated by Saka and Haque (1993) as follows.

$$\text{Degree of aggregation} = (Wp-Wo)/(Wa-Wo) \qquad (10)$$

where Wp is total weight of material retained on the sieve (g). Wa is weight of air dry soil (g). Wo is weight of coarse sand obtained from particle size analysis (g).

3.5.3.2 Degree and rate of dispersion

Five undisturbed soil aggregates (3 - 5 cm in diameter) were cautiously dropped into a 1000 ml beaker which was filled with water and observations on aggregate dispersion were made. The degree of dispersion was observed after 2 and 20 hours. The following scale was used to evaluate the degree of dispersion as stated by Loveday (1974); Kamara *et al.* (1992).

0 = no dispersion

1 = slight dispersion recognised by slight milkiness of the water adjacent to the aggregate plus the possibility of narrow edging of the dispersed clay to part of the aggregate after 20 hours.

2 = moderate dispersion clearly visible.

3 = strong dispersion with considerable milkiness and about half of the original aggregate dispersed.

4 = complete dispersion leaving only sand grains in a cloud of clay.

The dispersion index (DI) was estimated by summing up the dispersion marks. Qualitative comparison of dispersion was done by using a solution of $CaCl_2.2H_2O$ in which no dispersion occurred.

3.6 Determination of hydrological properties of the soil

3.6.1 Gravimetric soil water analysis.

Soil samples from rows and interrows were dried in the oven at 105^0C for 20 hours, cooled in a desicator and weighed. Water content, θg, was calculated as the ratio of the water loss on drying to the oven dry mass (Kamara et al., 1992; Saka and Haque, 1993).

3.6.2 Volumetric soil water content

The volumetric water content (θv) was determined from field soil samples by finding the product of the gravimetric water content and the bulk density of the respective layer as follows:

$$\theta v = \theta g \times \rho_b/\rho_w \qquad (11a)$$

where θv is volumetric soil water content (cm^3/cm^3). θg is the gravimetric water content (g/g). ρ_b is the bulk density of the soil (Mg/m^3). ρ_w is density of water assumed to be 1.00 (Mg/m^3).

The weighted mean profile water content for each treatment was calculated by the summation of the product between volumetric water content for each layer and respective depth as follows:

$$\theta p = \sum_{z_0}^{z_i} \theta v.\delta z \qquad (11b)$$

where θp is mean profile water content (cm^3/cm^3) in 0 - 45 cm depth; δz is the profile depth (cm) with similar textural class in which the matric potential and estimated water content is expected to be constant and i ranges from 1,2,3; z_0 and z_i is depth integral from the surface. θ_v is soil volumetric water content at 0 - 15, 15 - 28 and 28 - 45 cm depth.

3.6.3 Measurement of the low soil suction

Measurement of low suctions in this project was done by using tensiometers model 2900F1.

3.6.3.1 Recharging the Tensiometers.

The tensiometers (Model 2900F1) were recharged by filling the handle with clean water using a spoon whilst the porous tip was dipped in water. The null knob was opened until the red mark was visible. The vaccum gauge would drop to zero and the probe was ready to be used in the field.

3.6.3.2 Field calibration of tensiometers

The tensiometers (Model 2900F1) were set in the field at the following depths: 0 - 15 cm, 15 - 28 cm and 28 - 45 cm depth. Soil samples were collected at respective depth to determine the water content after each matric potential reading. The conversion of soil matric potential (μ) to the estimated soil water content in the profile (θv) was done by using the relationship between suction and water content by Visser (1969) which is expressed as:

$$\theta v = a\mu^{b} \tag{12}$$

where θv is the soil water content (cm^3/cm^3). (a) relates to the soil moisture characteristics of the given horizon. (μ) is the tensiometer reading in bars. exponent (b) relates to profile characteristics.

Tensiometers were calibrated by plotting $\log_{10}$ (volumetric water content) against $\log_{10}$ (suction) for the three textural changes in the profile i.e 0 -15 cm. 15 - 28 cm and 28 - 76 cm as shown in Figures 5a. 5b and 5c. By least square method. the regression constants in Table 2 indicated very good correlation between volumetric soil water content and matric potential. The regression constants were fitted into equation 12 to estimate the volumetric water content for the three textural classes defined in Table 1. The estimated soil water content on rows. interrows and 2/3 distance from interrows at 0 -15 cm. 15 -28 cm. and 28 - 45 cm are reported in Appendices 3a. 3b and 3c respectively.

3.6.3.3 Field soil water determination

Field measurements were done on each treatment by using an array of tensiometers. Holes were drilled using a coring tool to the following depths: 5. 20. 30 and 45 cm on rows (ridge top) on the interrows (centre of the furrow) and at the base of the ridge (distance 2/3 from the interrows). The tensiometers were inserted into the holes at the three sampling sites with great care to ensure smooth contact between the ceramic tip and the soil. The equipment was allowed to equilibrate for 15 minutes until the dial gauge showed no further movements. The reading was then recorded in centibars. This was the matric potential of the soil.

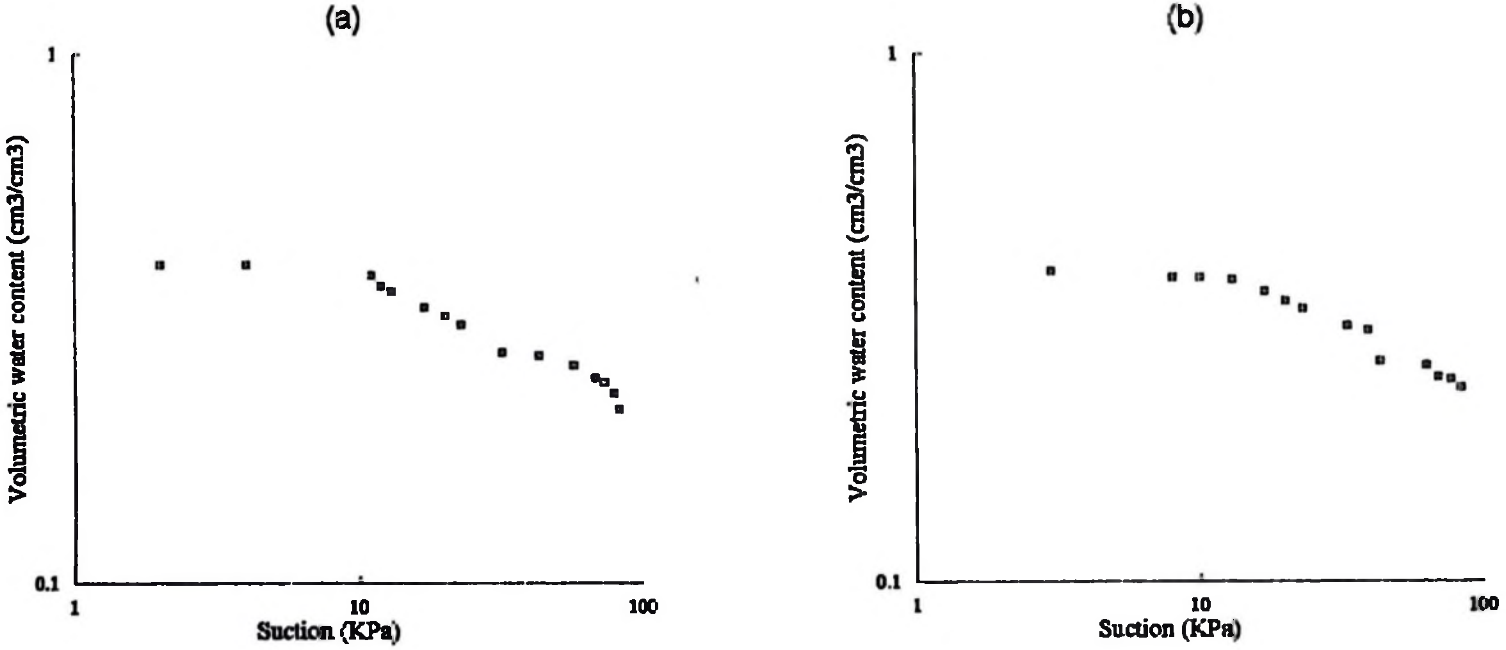


Figure 5a. Calibration of tensiometer (model 2900F1) at 0 - 15 and 15 - 28cm depth (b).

Regression Output:

Constant		-0.247
Std Err of Y Est		0.0225
R Squared		0.8276
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	-0.152	
Std Err of Coef.	0.0231	

Regression Output:

Constant		-0.318
Std Err of Y Est		0.0171
R Squared		0.855
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	-0.103	
Std Err of Coef.	0.0142	

(c)

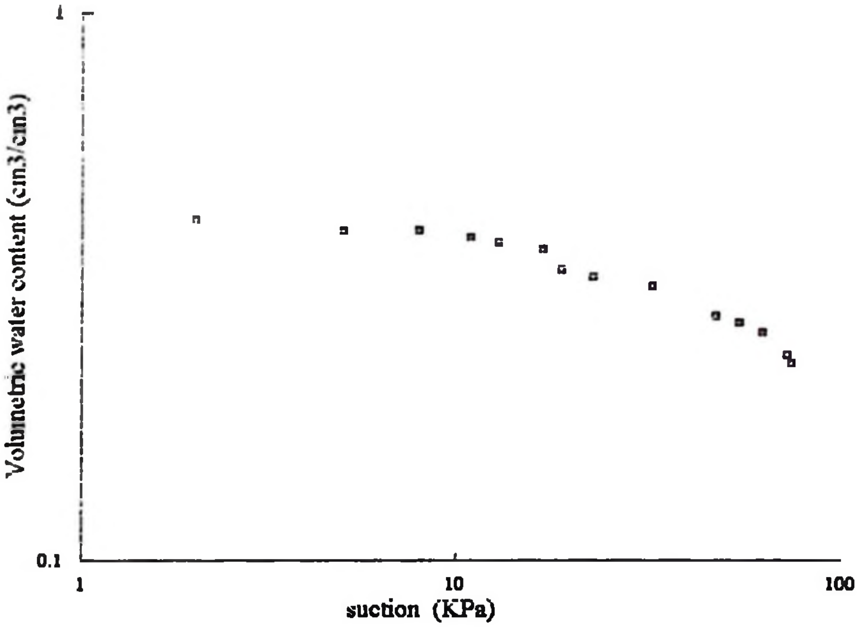


Figure 5c. Calibration of tensiometer (model 2900F1) at 28 - 45 cm depth.

Regression Equation

Regression Output:

Constant		-0.359
Std Err of Y Est		0.0349
R Squared		0.5931
No. of Observations		10
Degrees of Freedom		8
X Coefficient(s)	-0.076	
Std Err of Coef.	0.0224	

Table 2 Calibration of Tensiometer (Model 2900F1)

depth	a	s.e.	b	r	s.e.
0-15cm	-0.247	± 0.022	-0.152	0.920	± 0.023
15-28cm	-0.318	± 0.017	-0.103	0.924	± 0.014
28-76cm	-0.359	± 0.035	-0.076	0.770	± 0.022

where a and b are the regression constants. s.e. is standard error of the regression constants and r is correlation coefficient.

3.6.3.4 Soil water release characteristics

Core samples for soil water release characteristics were collected from 2 layers: 0 - 5 cm and 15- 20 cm depth from all treatments using a core sampler. The core samples were wrapped at one end with a piece of polyester cloth and saturated overnight on a porous plate of the Haines apparatus. When the required saturation levels were achieved, the core was removed from the Haines apparatus and transfered to a pressure plate extractor. The samples were subjected to the following progressive pressures: 0.1 bar, 1 bar, 2 bars until they were at equilibrium with the surrounding atmosphere. At the end of 2 bars equilibration the cores were dried in an oven at 105°C for 24 hrs and final weight was recorded (Klute, 1986).

For higher tension, (>2 bars) disturbed soil samples were used. Samples were put in rubber rings (3.5 cm in diameter) onto a porous plate and saturated with water. The samples were then progressively subjected to pressures of 3 bars, 5 bars 10 bars and 15 bars until the samples were at equilibrium in each stage (Saka and Haque 1993). Some samples were slow to respond due to compaction and resampling had to be done. The following calculations were made:

$$\theta g = [M1\text{-}M2/M2] \times \rho_b/\rho_w \qquad (13)$$

Where: M1 is mass of wet soil at θ_{fc} or at θ_{wp} (g), M2 is mass of oven dry soil (g), ρb is soil bulk density (Mg m^{-3}), ρw is density of water taken to be 1.00 Mg m^{-3} with an error of 0.2% at 20°C.

3.6.3.5 Saturated hydraulic conductivity

Core samples collected from 0 - 5, 15 - 20, 35 - 40 and 60 - 65 cm, were covered at the base with a muslin cloth fixed with a rubber band. The samples were placed with the cloth covered end down in a tray which was filled with water to a depth just slightly below 5 cm. The cloth protected the soil from dispersion and thus preventing the alteration of the soil structure. The samples were left to saturate for 24 hours or more until full saturation was achieved. The samples were allowed to drain for 2 hours and were placed in metal cylinders perched on wooden rack as shown in Figure 6. Whartman filter paper trimmed to core size diameter (5 cm) was put on top of all cores

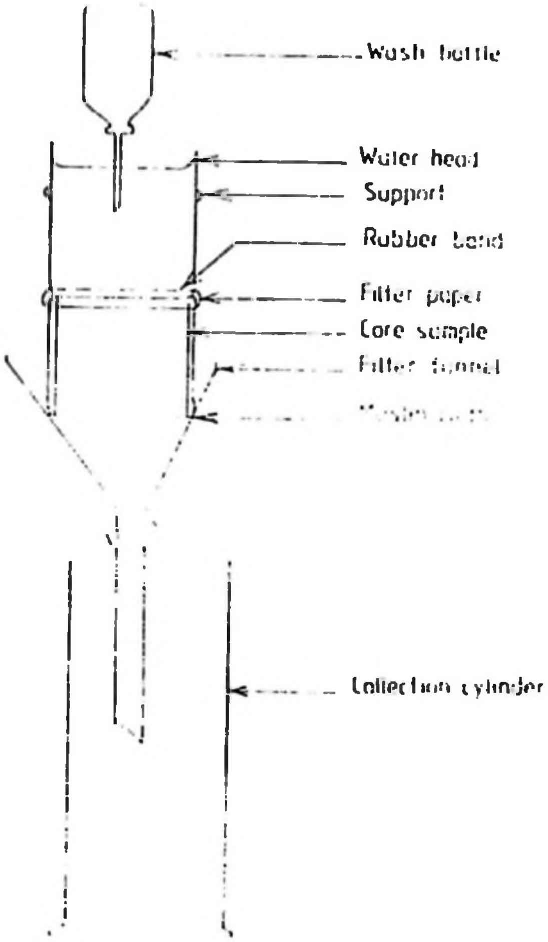


Figure 6. Saturated hydraulic conductivity apparatus

to prevent the initial trickle force of water from scouring the soil core. A hydraulic head was created by placing wash bottles filled with an equal volume of water on top of each cylinder creating a constant 1 cm hydraulic head. Measuring cylinders (100 ml) were set underneath the wooden trap to collect the percolate at a recorded time interval (Green *et al.*. 1986 and Saka and Haque. 1993). Hence saturated hydraulic conductivity (Ks) was calculated by using equation below:

$$Ks = Q\ At \cdot L\ H_1-H_2 \qquad (14)$$

where Q is volume of percolate collected in the measuring cylinder. t is time interval (min). H_1-H_2 (δH) is length of soil column (5 cm) plus a water head (1 cm). L is length of the soil layer. A is the cross sectional area of the core (cm^2).

3.6.4 Estimation of drying rates of the soil.

The drying and recharge coefficients were estimated by using equation 4 after Van Wessenbech and Kachanoski. (1988) and Zhai et al. (1991):

$$k_i = -\ln\theta_{it}\ t\ln\theta_{i0} \qquad (15)$$

where k_i is the drying rate constant which is calculated as the decline in profile water content with time and i stands for row. interrows and 2/3 from interrow. θ_{it} is soil water content within a defined depth at relative time t (days) θ_{i0} is the initial soil water content defined at the beginning of the drying period (t 0) after a recharge event.

3.6.5 Infiltration rate

Infiltration rate measurements were conducted on each treatment prior to the heavy rains and after harvesting. The Double ring method by Saka and Haque (1993) was used. The inner ring was 28 cm in diameter whilst the outer ring was 53 cm in diameter. Both rings were 35 cm high and were driven into the soil to a depth of 15 cm by using a sledge hammer. This operation was done with utmost care to prevent disturbance of the soil. A plastic sheet was placed in the inner cylinder to act as an anti - puddling device. Water was introduced into the inner ring and the plastic sheet was removed. The maximum and minimum water levels were maintained at 12 cm and 6 cm above the soil surface in both rings. For each treatment, two sets of measurements were made and readings were collected for at least 3 hours until a steady state flow was reached.

3.6.6 Runoff Measurement

3.6.6.1 Calibration of runoff drums/tanks.

Runoff drums were calibrated with predetermined volumes using small 12 litre buckets. The buckets were filled with water and emptied into the drums. Measurement of runoff collected in the drum was done by multiplying the number of buckets decanted by 12 litres.

3.6.6.2 Installation of runoff tanks

Runoff water collection tanks (200 litres in capacity) were installed at the edges of each plot along the channel separating the replicates as shown in Figure 4. Drums were inserted in holes dug 60 cm in diameter and 90 cm deep. The space between the tank and margins of the pit was sealed with soil extracted from the pits.

3.6.6.3 Runoff data collection.

Runoff measurement was done by using 12 litre buckets to empty water from tanks and is reported as cummulative runoff events. Corrections for channel runoff contribution and direct precipitation were made. In this study, estimates of surface runoff water from experimental plots were made based on the following assumptions:

(a) That there existed no spatial and temporal variations in rainfall distribution within the experimental field. In this respect, the amount of rainfall received per unit area in a given time was uniform.

(b) That evaporation losses from runoff collection tanks were negligible. This assumption was based on the premise that all runoff readings were made soon after rainfall events. For rainfall events occurring at night, runoff measurements were done early in the morning.

(c) That a simplified water balance relationship based on Hillel (1980) will be applicable as follows: Precipitation - Infiltration = Runoff.

3.7 Soil temperature

Soil temperature measurements were made at two depths, 3 cm and 20 cm, on both ridge top (rows) and furrow or basins centre (interrows). Soil temperature readings were made twice a week from November to April on all the treatments by using glass mercury thermometer (0 - 50°C). The mercury thermometers were inserted directly into the ridges and furrows and readings were between 12.00 - 15.00 hours. The results are summarised as the average monthly maximum soil temperatures for the time of the experiment.

3.8 Maize growth and yield parameters

3.8.1 Plant growth and yield

During the growing season, plant height and number of leaves were recorded. The data were collected from 5 randomly chosen plants which were labelled with a metal tag. Growth rates were monitored on these same plants. Plant height was measured from the soil surface to the top most leaf. Plant samples were taken at 100% tasselling and at near harvesting time to determine the leaf area by using the leaf area meter. The plant samples were chopped and dried in the oven at 80 degrees celcius for 48 hours and dry matter yield was determined. Other phenological developments recorded included days to the first tasselling and days to 100% tasselling.

Before harvesting, the number of plants in each plot was counted. Harvesting was done from the net plot consisting of 4 rows measuring 5.4 m long making a net plot of 12.96 m^2. Guard rows were not harvested on all plots Harvesting began when 98% of the crop had matured. Harvesting was done by cutting the base of the plant. A total of 15 plants were drawn from each plot to determine the dry plant weight. The cobs were first dried in the sun before removing the panicles. Then they were shelled manually and seeds were dried for two weeks. A sample of 200 grams of seeds was collected from each bag to determine the moisture content and a final grain weight for each treatment was adjusted by using a correction factor due to variation in stand count at harvesting.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil characterization.

The results of soil profile description and chemical analysis are reported in Appendix 1a and 1b, respectively. The soil has low residual nitrogen and organic carbon content. The sodium content decreases with depth from about 0.09 me/100g in the A_p horizon to 0.05 me/100g in B_{ts}. The soil is acidic with an average pH of 5.5 in the plough layer and CEC and exchangeable bases were higher in 0 - 25 cm depth than in subsequent horizons. Organic C, total N and available P also decreased from about 1.08%, 0.11% and 13 mg/g in 0 - 25 cm depth respectively (Appendix 1b).

Textural analysis indicates a general increase in clay with depth from 33% in the 0 - 15 cm depth to 69% at 76 - 115 cm depth. A significant proportion of sand in the 0 - 15 cm and 15 - 28 cm depth makes the aggregates friable and thus slake upon rain drop impact. Saturated hydraulic conductivity decreases with depth from 0.76 cm/h in the 0 - 15 cm depth to about 0.056 cm/h above 76 cm depth as indicated in appendix 1b.

4.2 Agrometeorological data analysis

4.2.1 Rainfall

Figure 7a. gives the pattern of rainfall distribution in the season subjected to 5 day averages (pentade analysis in Appendix 2b). The depressions occurring in the chart between pentade 1 - 6, pentade 10 - 13, pentade 29 - 30, 34 - 35 and pentade 37 - 41 are the dry spell periods which occur intermittently within the rainy season.

4.2.2 Rainfall intensity

The frequency distribution for the mean 30 and 60 minute maximum rainfall intensity are plotted against number of pentades in Figure 7b. In most instances the RI_{30} storms were quite erosive and generated significant runoff from the experimental plots save for pentades 20 and 25 in which substantial 60 minute rainfall intensities were received.

4.2.3 Rainy days and dry spells.

Figure 7c gives the distribution of rainy days and dry spells occurring within the crop growing period. The data in appendix 2b indicates a normal distribution for both rainy days and dry spells in a unimodal rainfall pattern as reflected in the 42 pentades analysed during the season. There is about equal distribution of rainy and dry days in

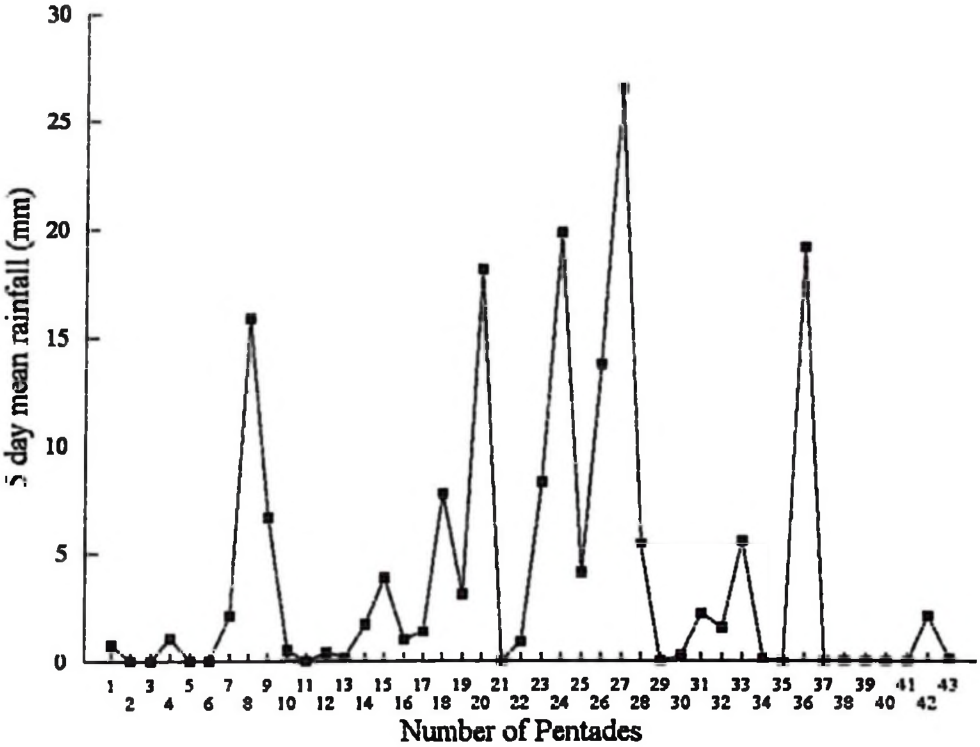


Figure 7a Plot of five day mean rainfall versus No. of pentades

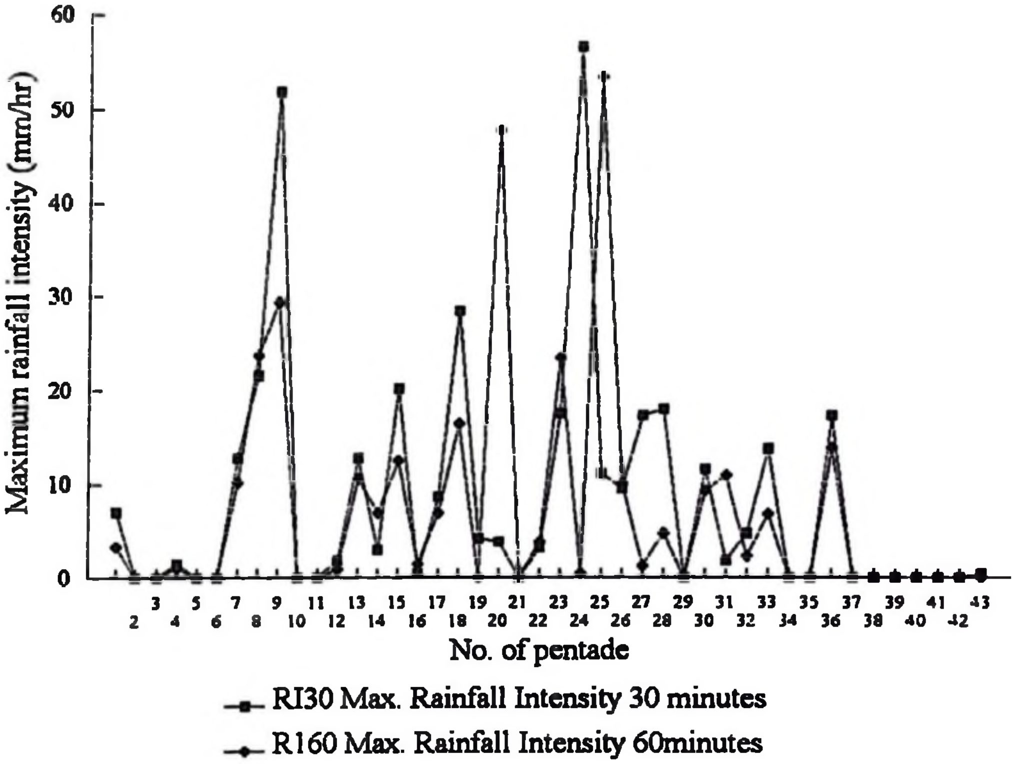


Figure 7b. RI30 and RI60 distribution versus No. of pentade

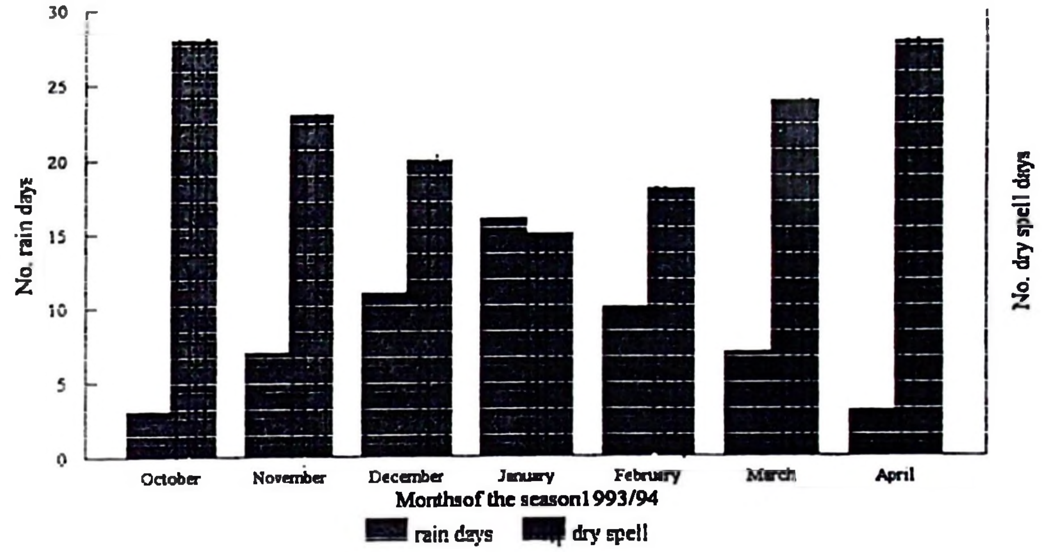


Figure 7c. Seasonal distribution of rain days and dry spells

the month of January. In this season, January was the wettest month while October and April were the driest months of the season. The dry spells were of longer duration than the rainy days giving a probability of having a complete pentade of dryness of about 36% (Table 3). The occurrence of the dry spells in October is normal in this region and and the whole Lower Shire and Thyolo escarpment indicated on Figure 3. The rainy season for the year under consideration started late and ended early. It is apparent from this analysis that the shortest dry spell was experienced in January giving about 2% probability of having a complete pentade without a dry day.

Table 3: **Ranking dry spells frequency to pentades**

Ranking indices	Frequency	Probability
5	15	0.36
4	7	0.17
3	8	0.19
2	10	0.24
1	1	0.02
0	1	0.02

Ranking Indices 0 indicates pentades without a dry spell (Precipitation 0.5 mm) and 5 indicates a complete dry pentade (Precipitation 0.5 mm).

4.2.4 Air and soil temperature measurements.

Appendix 2a gives a summary of agrometeorological data of Bvumbwe Research Station. The highest air temperatures were recorded in October and November. This coincided with the cultivation period leading to severe dessication of the soil. Maximum soil temperatures read at 3 cm depth were higher on the ridges (Figure 8a and 8b) than on the furrows (Figure 8c and 8d). Soil temperatures were higher at 0 - 5 cm depth than at 20 cm depth. Following the heavy rains received in January, soil temperatures were lowest in BR at all depths followed by TR whilst OR was equal to RR as shown in Figures 8a - 8d. The surface layers dried faster in cultivated rows. The variation in soil temperature between treatments may be partly due to the cooling effect (damping effect) by soil water in the profile and partly due to gravitational drainage related with ridge height i.e. the 30 cm row (OR, BR, TR) were draining faster than the 10 cm residual ridge. Similar results on soil temperatures in a ridge - furrow system have been reported by Mahrer and Avissar (1985) and Gupta *et al.* (1990).

4.3 The effect of traditional cultivation practices on soil physical properties

4.3.1 Dry bulk density

Dry bulk density measurements prior to tillage operation are reported in Appendix 1b. Table 4 and 5 give row and interrow dry bulk densities just soon after cultivation

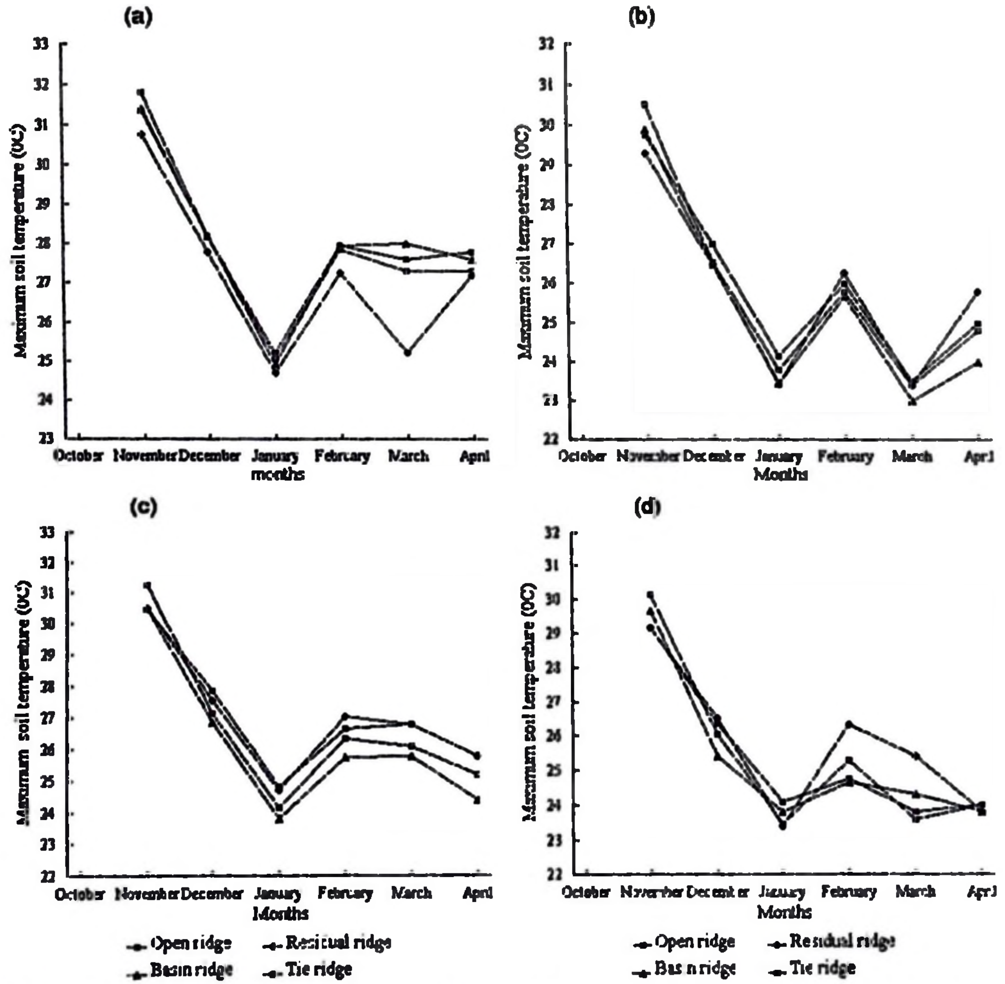


Figure 8 Maximum mean soil temperature at 3 cm and 20 cm depth in rows (a) and (b) and at interrows (c) and (d) respectively.

(initial) and after harvesting (final). The dry bulk density on RR rows were slightly higher with a mean dry bulk density of 1.35 Mg m^{-3} within the 0 - 5 cm depth, whereas the mean dry bulk density of 1.28 Mg/cm^{3} was measured in treatments OR, BR and TR. Below 15 cm depth, dry bulk density variation on rows were not systematic. By harvesting time, row dry bulk density increased by 0.02 Mg/m^{3} on RR whereas an increase of about 0.08 Mg/m^{3} was noted in treatments OR, BR and TR, (see Table 4). Therefore, dry bulk density on rows increased by 5% within the 0 - 5 cm depth in treatments OR, BR and TR whilst in treatment RR, dry bulk density increased by approximately 1%. Row dry bulk density readings were significant within the 0 - 5 cm depth soon after cultivation. But there were no significant difference between treatments OR, BR and TR. Interrow dry bulk density within 0 - 5 cm depth were not significantly different at 5% probability level (Table 5). The highest interrow dry bulk density readings were recorded on BR treatment and ranged from 1.41 to 1.45 Mg m^{-3} may be due to compaction and smoothness created by the hoe during basin preparation.

There was a general increase in dry bulk density with depth in all treatments as indicated in Tables 4 and 5. Two possible explanations to this trend are: (1) there is gradual increase in clay content with depth as indicated in Table 1. (2) The higher readings at depth beyond 30 cm may be due to the presence of plough pans/soles which have been preserved from previous cultivation processes with tractor drawn implements. Since hand hoe cultivation is limited to the 0 - 10 cm depth these plough pans were not broken by the current traditional tillage practices.

Table 4 Effect of tillage on dry bulk density (Mg/m^3) on rows at different soil depths

depth	5 cm		15 cm		30 cm		45 cm	
	1st.	last	1st.	last	1st.	last	1st	last
Reps.	NS	NS	NS	NS	*	NS	*	NS
Treat.	*	NS	NS	NS	*	NS	NS	NS
OR	1.28^{b}	1.36	1.37	1.39	1.43^{b}	1.43	1.40^{b}	1.48
RR	1.35^{a}	1.37	1.37	1.44	1.45^{a}	1.42	1.42^{a}	1.47
BR	1.28^{b}	1.36	1.37	1.40	1.40^{c}	1.41	1.40^{b}	1.49
TR	1.29^{b}	1.35	1.37	1.42	1.39^{c}	1.48	1.42	1.47
s.e.	0.018	0.0	0.018	0.0	0.0	0.018	0.0	0.018
c.v.(%)	2.38	1.49	1.80	1.56	1.27	2.15	1.56	1.71

NS Not Significant ($P > 0.05$)

* Significant ($P < 0.05$)

Means with superscipts are significantly different at 5% probability level by using the Duncan's New Multiple Range Test.

Table 5 Effect of tillage on dry bulk density (Mg/m^3) on interrows at different soil depths

period	1st	last	1st.	last	1st	last	1st	last
Depth	0-5	0-5	10-15	10-15	25-30	25-30	40-45	40-45
Reps.	NS	NS	NS	NS	NS	NS	NS	NS
Treat.	NS	NS	NS	NS	*	NS	*	NS
OR	1.38	1.41	1.39	1.43	1.39^c	1.43	1.40^d	1.41
RR	1.40	1.41	1.39	1.42	1.39^c	1.41	1.42^c	1.43
BR	1.41	1.43	1.41	1.44	1.44^a	1.44	1.45^a	1.45
TR	1.39	1.42	1.41	1.40	1.42^b	1.43	1.43^b	1.43
LSD			0.032		0.032			
s.e			0.009		0.009			
c.v(%)	1.43	0.97	0.75	1.54	0.97	1.10	0.79	0.90

NS Not Significant ($P > 0.05$)

* Significant ($P < 0.05$)

Means with superscipts are significantly different at 5% probability level by using the Duncan's New Multiple Range Test.

A similar trend of results has been reported by Cassel (1980), Adeoye (1982), Kayombo (1986), Cresswell et al. (1991) and by Agenbag and Maree (1991) with conventional tillage practices.

4.3.2 Total porosity and macroporosity

Total porosity (S_t) and macroporosity for each tillage practice are shown in Appendices 4a and 4b. There is a general decrease in total porosity with depth. However, total porosity in 0 - 5 cm depth is higher in OR, BR and TR than RR with a mean of about 51% and 49% respectively. Below 5 cm depth variations in total porosity were not systematic. The net drop in total porosity measured at harvesting time was about 3% on rows in OR and BR and 2% in TR whereas the net drop of about 0.38% were measured in RR treatment. Interrow total porosity had marginally dropped to about 1% in all treatments but the drop was not systematic. Mean row macroporosity within the 0 - 5 cm depth was 24% on OR, BR and TR whereas 21% in RR. Changes in macroporosity within 0 - 5 cm depth corresponded with the reduction in total porosity. The drop in both total porosity and macroporosity may be due to clogging of pore spaces by fine soil washed down with infiltration and/or slumped down due to raindrop impact. In the residual ridges, lack of soil disturbance justifies the lower values of total porosity.

Similar results were reported from ferrallitic soils of Senegal by Nicou et al. (1986); on the Griswold silt loam soil by Datiri and Lowery, (1991); and Unger and Cassel, (1991).

4.3.3 Aggregate stability

Aggregate stability values reported in Table 6 are means of 5 samples per treatment. The data show that aggregate stability increased with depth. The reason for this trend is that the traditional cultivation practices using a hand hoe were limited to the (0 - 10 cm) depth. Therefore the presssure exerted on soil by tillage practices had greater impact on surface (0 - 5 cm) layers. The distribution of stress diminished with depth leading to marginal weakness on the aggregates at higher depth. Analysis of variance on aggregate stability is statistically significant at 5% probability level with aggregate stability being 5% higher in RR compared to OR, BR and FR. Aggregate stability in treatments OR, BR and FR was not significantly different as indicated by the Duncan's New Multiple Range Test in Table 6. The higher values on stability and lower values on Dispersive Index (DI) in RR (Appendix 4e) are probably associated with a high organic matter content. Increase in clay content and Fe and Al oxides with depth (Appendix 1b) could also have a significant effect in binding the aggregates. Reduction in aggregate stability at harvesting in RR could have been associated with secondary cultivation practices during weeding and raindrop impact. Similar relationships on aggregate stability variation with depth and time have been observed by Unger and Cassel (1991) under conventional tillage practices.

Table 6 Summary of analysis of variance on aggregate stability

sampling period	18-11-94	4-4-94	18-11-94	4-4-94
Depth	0-5	0-5	10-15	10-15
Reps.	NS	NS	NS	NS
Treat.	*	*	*	*
OR	19.14^{c}	20.08^{c}	22.96^{b}	19.54^{c}
RR	24.78^{a}	25.02^{a}	25.39^{a}	25.07^{a}
BR	20.69^{c}	20.40^{c}	22.05^{b}	20.22^{b}
TR	20.74^{c}	20.08^{c}	21.40^{b}	20.20^{b}
LSD	1.027	0.905	0.503	0.459
s.e.	±0.297	±0.262	±0.145	±0.133
C.V (%)	4.82	2.35	3.95	2.16

NS Not significant ($P > 0.05$).

* significant ($P < 0.05$).

Means with superscripts are significantly different at 5% probability level by the Duncan's New Multiple Range Test.

4.4 Hydrological properties of the soil at the experimental site

Appendices 5a and 5b show soil water retention characteristics curves at 0 - 5 cm and 20 - 25 cm depth, respectively. There was no significant variation in water retention characteristics. Treatment RR had lower water content at saturation but held more water at higher tensions than 50 kPa (Appendix 5b) probably due to a well preserved structure. But at extremely higher tension (> 1000 kPa) tillage operation did not influence the soil water retention characteristics.

Saturated hydraulic conductivity values (Appendix 1b) decreased with depth i.e. from 0.76 cm ha at 0 - 15 depth, 0.57 cm h at 15 - 28 cm depth, 0.23 cm h at 28 - 76 cm depth and 0.056 cm h at 76 - 115 cm depth.

4.4.1 Correlation between gravimetric and estimated profile water content

Table 7 shows relationship between profile soil water content in rows determined gravimetrically and profile soil water content determined by the Tensiometer (Model 2900F1). The results show good correlation coefficients of about 0.88 for rows and about 0.92 for interrows (Table 7).

The tensiometer, (model 2900F1), over - estimated the profile water content at higher suctions (Figure 9). At lower tension (< -15 kPa) the tensiometer readings compared favourably with gravimetric determinations giving high fairly similar results as

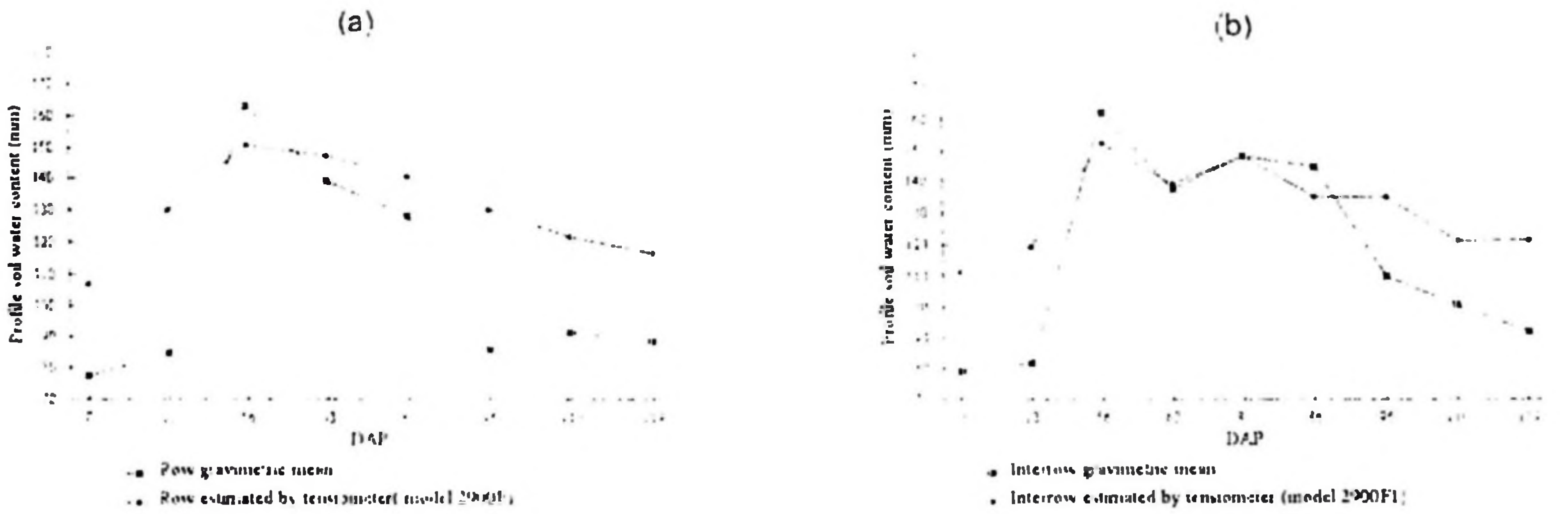


Figure 9 Comparing gravimetric and estimated profile water content in rows (a) and interrows (b).

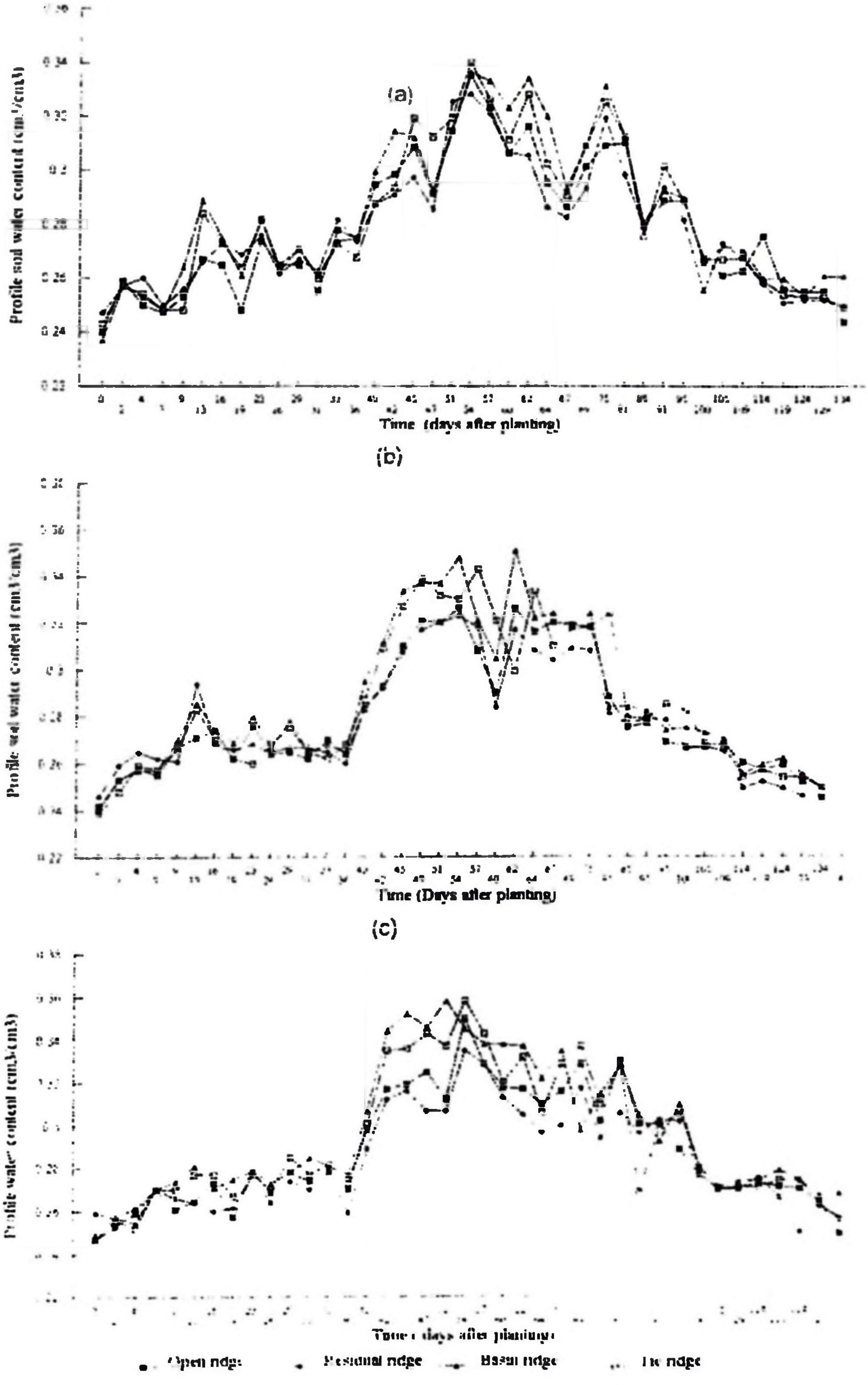


Figure 10 Weighted mean profile soil water fluctuations in rows (a) 2/3 distance from interrows (b) and in interrows (c) in relation to recharge and drying cycles during the growing season

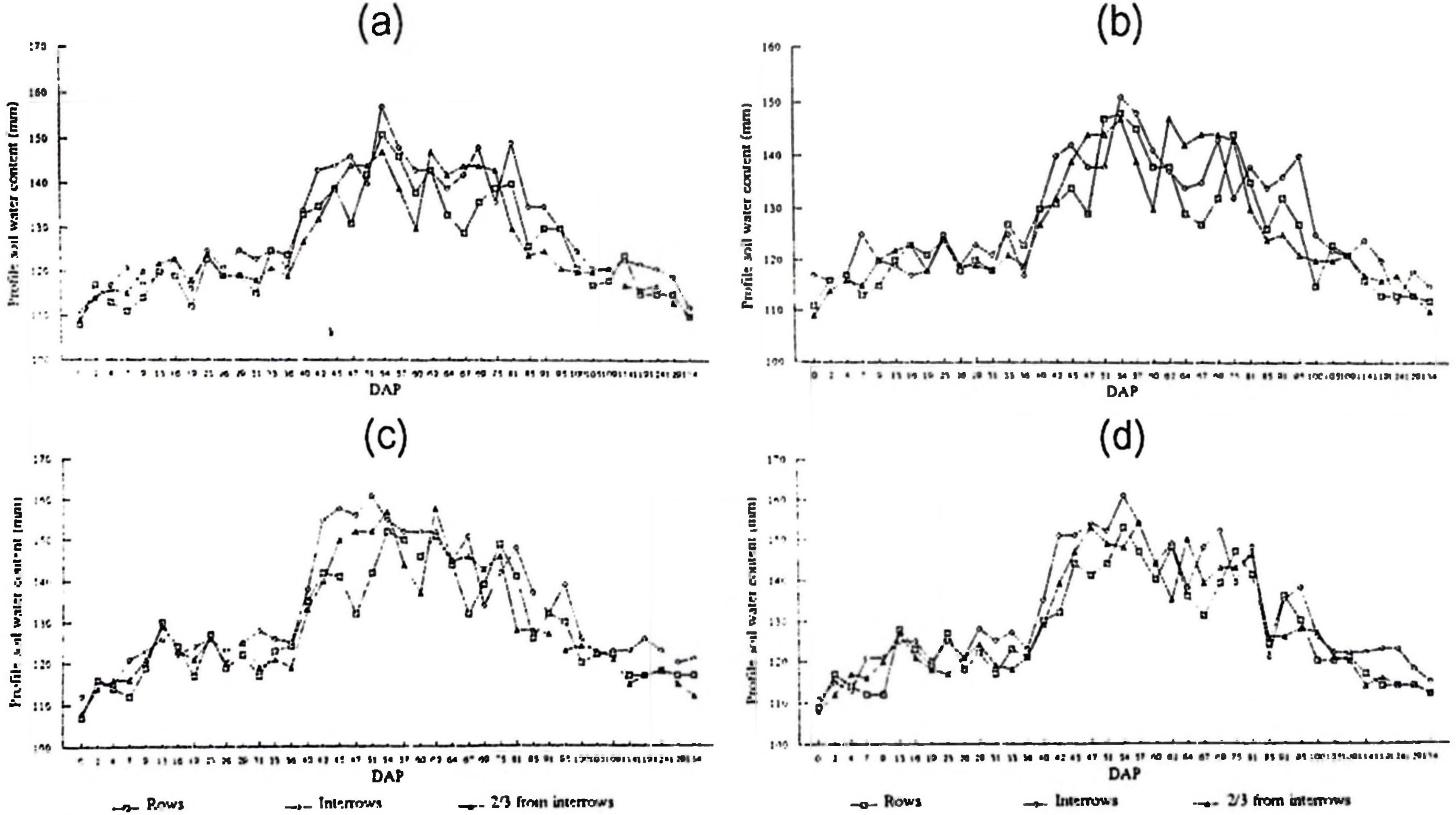


Figure 11 Profile soil water content between rows, interrows and 2/3 distance from interrows in OR (a), RR (b), BR (c) and TR (d) treatments.

each treatment shows a seasonal trend. The highest difference in moisture content exists in BR seconded by TR treatments. This may be partly associated with the depressional storage and low runoff discharges in these treatments.

4.4.4 Variations in mean profile water content between treatments.

Figure 12a gives variations in row soil water content between the main treatments and RR. In OR and RR, the seasonal trend was not obvious. In many instances the θ_r(OR) was lower and/or equal to θ_r(RR). The θ_r(BR) - θ_r(RR) and θ_r(TR) - θ_r(RR) were positive and showed a remarkable seasonal trend (Figure 12a). There were small differences in soil water content in the early stages of growth, followed by significant rise in the differences in row soil water content in January February and a drop at the end of the season (March and April). In the early stages of crop growth, there was no canopy to protect the soil from direct solar radiation. Hence, there were substantial losses in soil water through direct evaporation. The high water content at tasselling, silking and ear development stages was due to high rainfall received in January and February and the development of sufficient vegetative cover which limited evaporation losses but promoted recharge through interception and stem flow. The large difference in BR is associated with basin storage. At the end of the season, crop senescence coupled with the dry spell from March to April, lowered the soil water content. Pronounced effects of cultivation practices were observed on the

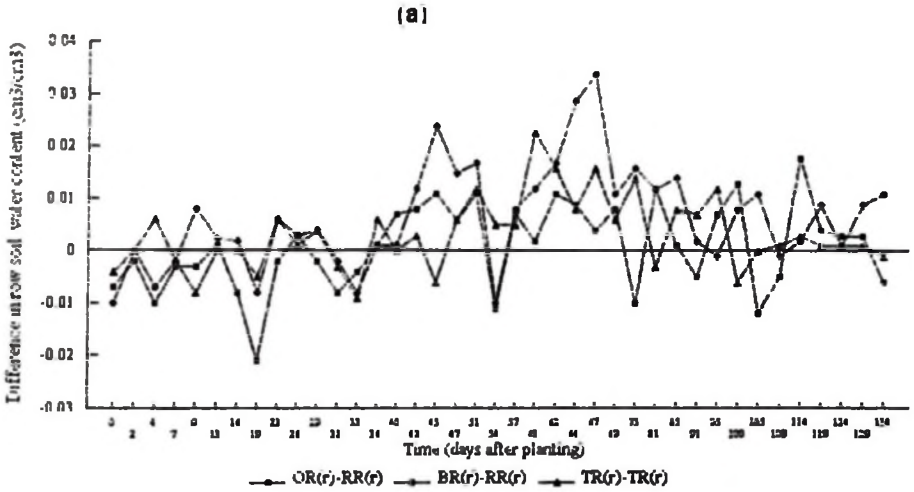


Figure 12a The difference in row soil water content between open ridge and residual ridge, basin ridge and residual ridge, tie ridge and residual ridge.

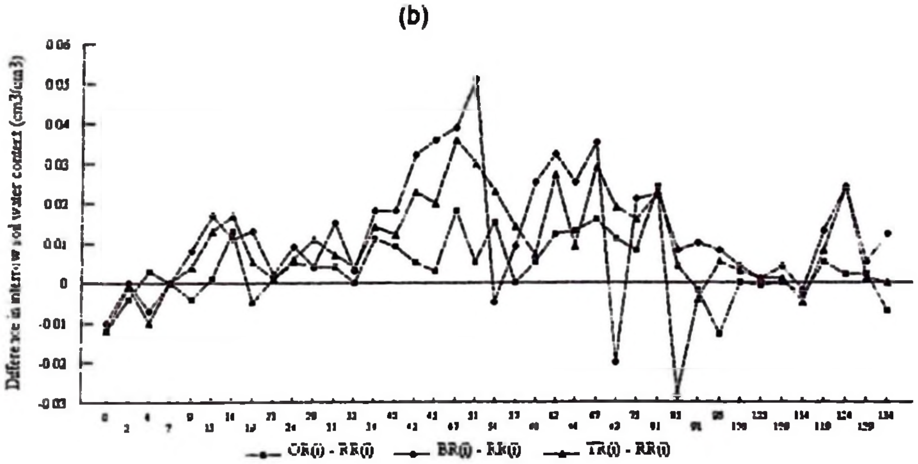


Figure 12b. The difference in interrow soil water content between open ridge and residual ridge, basin ridge and residual ridge, tie ridge and residual ridge.

difference in interrow soil water content between treatments as indicated in Figure 12b. The trend in seasonal soil water content was as follows: $|\theta_i(BR) - \theta_i(RR)| > |\theta_i(TR) - \theta_i(RR)| > |\theta_i(OR) - \theta_i(RR)|$ and was always oscillating at an average difference of 8 mm, 5 mm and 3 mm, respectively. The decline in soil water content at 54 DAP was associated with secondary tillage practices during the weeding process. The decline in water content was larger in OR, BR and TR than in RR. This was related to the degree of soil disturbances during weeding.

4.4.5 Seasonal distribution of soil water recharge cycles at different textural classes within the profile.

Figures 13(a...i) give the relationship between volumetric water content and depth in rows and interrows at different crop development stages. These relationships show spatial and temporal distribution of recharge cycles in the treatments following rainfall events. The basic definition of recharge events is the general rise in soil water content.

4.4.5.1 Soil water distributions on rows at 0 - 45 cm depth

The mean soil water content on rows during planting to emergence period, (0 - 13 DAP), was higher on RR compared to BR, TR and OR (Figure 13a). Row

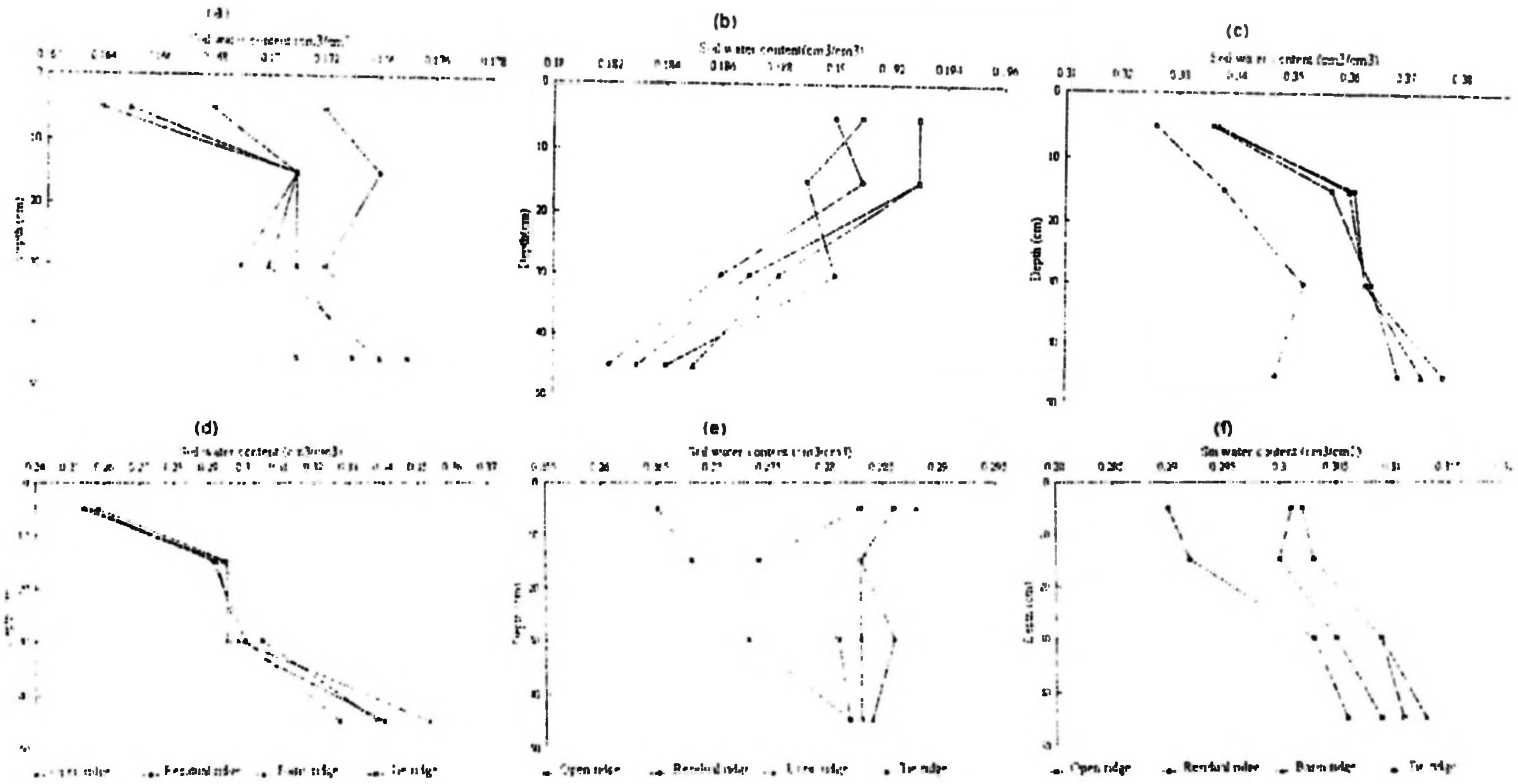


Figure 13 Row soil water distribution with depth at different crop development stages : (a) planting, (b) emergency (13 DAP), (c) tasselling (56 DAP) (d) tasselling (63 DAP) (e) silking and ear development (81DAP) and (f) silking and ear development (86 DAP)

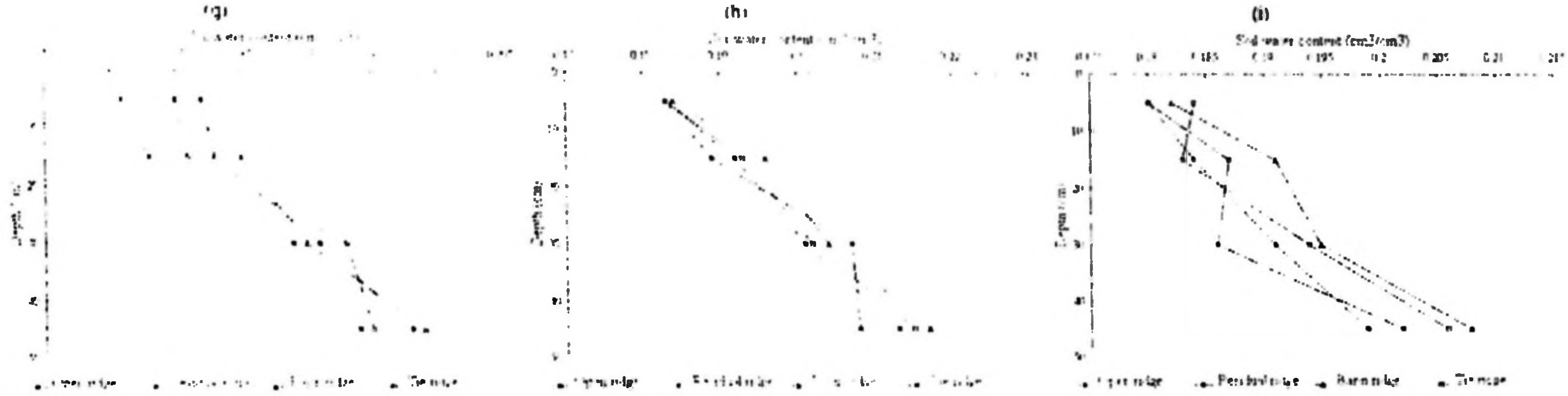


Figure 13 continued (g) maturity (96 DAP), (h) maturity (110 DAP) and (i) harvesting (119DAP) soil water content within 0 - 45 cm depth measured at tasselling, silking and ear development stages (56-86 DAP) was statistically significant at 5% probability level (Appendices 7e and 7f and Figures 13c, 13d, 13e and 13f).

Mean soil water content was higher in BR and the general trend was BR > TR > OR = RR. At maturity (96 - 119 DAP), row soil water content was not statistically significant between treatments 0 - 15 cm and 15 - 28 cm depth but was significant at 28 - 45 cm depth due to lateral recharge from basins and ties (Appendices 7g, 7h and 7i and Figures 13g, 13h, and 13i).

4.4.5.2 Interrow soil water distribution at 0 - 45 cm depth between treatments

The interrow soil water content at different growth stages is reported in Figures 14 (a..i). The variation in interrow soil water content, measured at 0 - 5 cm depth sampled from 0 - 13 days was statistically significant between treatments as shown in Appendix 11a. Variances in interrow soil water content from tasselling, (Figure 14c) silking to harvesting time, (Figures 14d, 14e, 14f, 14g and 14h) showed statistical significance between treatments at 28 - 45 cm

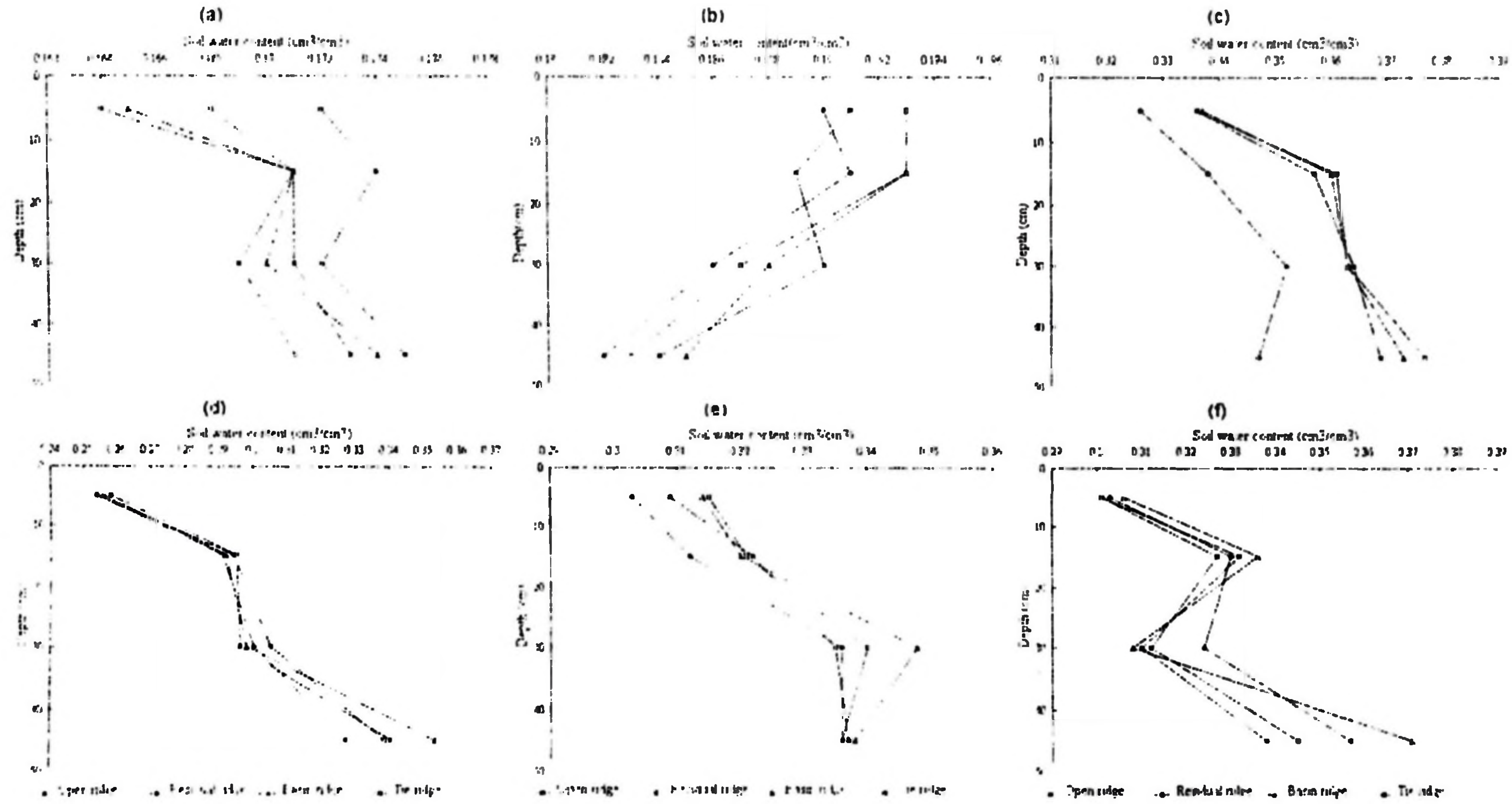


Figure 14 Interrow soil water distribution with depth at different crop development stages (a) planting, (b) emergency (13 DAP) (c) tasseling (56 DAP)
(d) tasselling (63 DAP), (e) silking and ear development (81 DAP) and (f) silking and ear development (86 DAP)

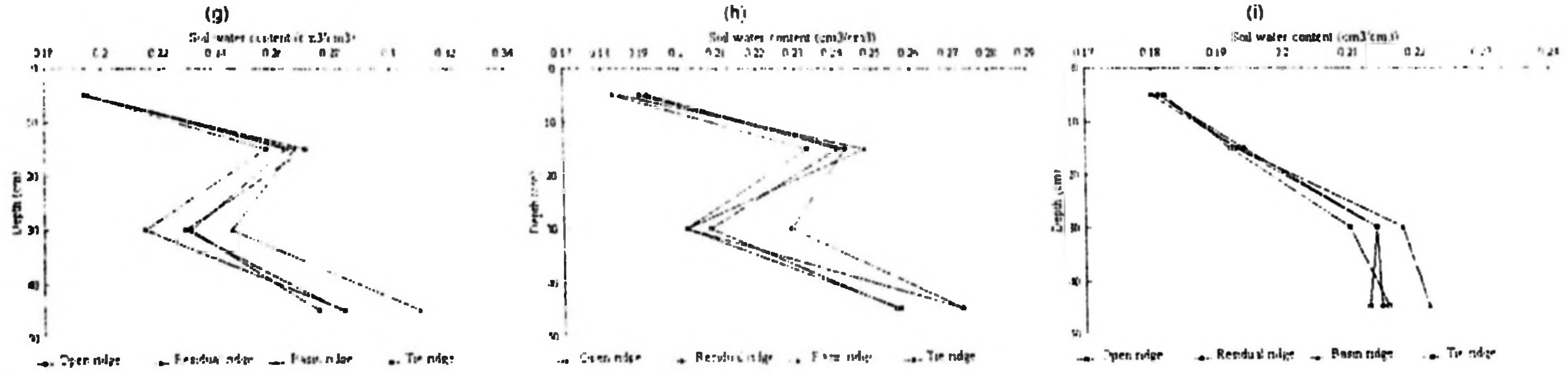


Figure 14 continued (g) maturity (96 DAP), (h) maturiy (110 DAP) and (i) harvesting (119 DAP)

(Appendices 8b, 8c, 8d, 8f, 8g, and 8h). Treatment BR maintained the highest soil water content in interrows at 13 DAP up to 142 DAP in 0 - 15 cm depth; from 13 DAP to 95 DAP at 15 - 28 cm depth and at 28 - 45 cm depth. This is attributed to depression storage whereas TR had a higher soil water content at 36 DAP to 70 DAP. Treatments OR and RR did not show a systematic trend.

4.4.6. Soil drying rates 0 - 5 cm depth.

The results of the drying coefficients at the rows (k_r), interrows (k_i) and at 2/3 distance from interrows k(2/3) for the 0 - 5 cm depth are presented in Table 8.

In all treatments, variation in drying coefficients at three sampling positions (rows, interrows and 2/3 from the interrows) showed a seasonal trend of drying coefficients being higher in the beginning of the season and dropping to < 0.200 d^{-1} at the end of the season. In many instances, the drying rates k_r were higher than k_i values between the crop development to about maturity time. The spatial variations in drying rates were not systematic. Prior to canopy development, the k_i values were higher than k_r. But also, drying rates in rows at 13 DAP asssumed the following trend: OR 0.441, RR 0.374, BR 0.421 and TR 0.416 d^{-1}. The lowest drying rates in RR treatment were presumably due to minimal soil disturbance and probably due to a low gravity head.

Table 8: The mean soil water coefficients k at different crop growth stages, spatial locations and tillage treatments. Sampling depth 0–5 cm)

[illegible]	[illegible]			[illegible]			Basin ridge			Tie ridge		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	k	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.483	0.416	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.318	[illegible]	[illegible]	0.309	[illegible]	0.318	[illegible]	[illegible]
25 28	0.296	[illegible]	0.313	[illegible]	[illegible]	[illegible]	0.307	0.325	0.298	0.311	0.318	0.319
[illegible]	[illegible]	0.435	0.480	0.473	[illegible]	[illegible]	0.491	0.435	0.470	0.441	[illegible]	0.461
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.319	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.187	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.192	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.182	[illegible]	[illegible]	[illegible]

[illegible] and ear development [illegible]

[illegible]

[illegible]

[illegible]

Therefore the drying phase can mathematically be expressed as a function of change in water content with time as follows:

$$\delta\theta/\delta t = \delta/\delta z\,(K\,\delta\mu/\delta z) + \delta K/\delta z \qquad (16a)$$

$$\text{Where } \delta\mu = \delta\mu_m + \delta\mu_g \qquad (16b)$$

δm_g is gravitational potential variations due to height of rows and due to positions of measurements. $\delta\mu_m$ is matric potential measured in rows, interrows and 2/3 from interrows and K is the unsaturated hydraulic conductivityof the soil. Incorporating the diffusivity (D) component gives

$$\delta q/\delta t = \delta/\delta z\,(D\,\delta\theta/\delta z) + \delta K/\delta z \qquad (16c)$$

where D is soil water diffusivity defined by the relation

$$D = K(\theta)\,(\delta\theta/\delta\mu) \qquad (16d)$$

But adopting transient recharges from low potential from interrows, the spatial variations in drying rates are represented as equation:

$$\delta\theta/\delta t = \delta/\delta x(K\,\delta\mu/\delta x)_i + \delta/\delta y(K\delta\mu/\delta y)_{ii} + \delta/\delta z(K\delta\mu/\delta z)_r + \delta K/\delta z. \qquad (16e)$$

where i = interrows, r = rows, and ir is interrow and row interaction.

The driving force for the distribution of water in the profiles is the hydraulic head which is a function of matric and gravity potential. After each rainfall event, flow of water from the wetted surface rows is almost vertically downward in response to gravity and the matric forces around the soil colloids.

Migration of the wetting front from low potential to higher potential can, unequivocally, be considered as a drying phase for the upper layer and yet becomes a recharge phase for the lower layers. The upward moisture fluxes in BR, TR and OR were grossly affected by the pore size distribution within the profile. Due to the initial disturbances by cultivation, the capillarity system in these treatments was reduced leading to rapid drying in rows in BR, OR and TR. Similar results have been reported by Arya et al. (1975).

Since both recharge and drying phenomena were occurring concurrently, the predominance of one phenomenon was temporal and depended on rainfall distribution, rainfall intensity and soil physical and hydraulic characteristics. Since rainfall input from October to the end of November was distributed as small short events, the drier tilled zones in OR, TR and BR were not fully recharged.

4.4.7 Analysis of spatial variance in soil water content

Table 9 indicates fairly significant correlations between spatial variance and mean soil water content with correlation coefficient of 0.52 in OR and RR, 0.54 in BR and 0.55 in TR. The storage capacity of each treatment was the source of variation in soil water content on rows, interrows and 2/3 distance from interrows. The migration of the wetting front, from low soil water potential in basins or interrows towards high soil water potential on rows eventually narrowed the spatial variance in soil water content between rows and interrows. Similar results have been reported on a Typic Hapludalf by Zhai et al. (1990) and Van Wesenbeeck and Kachanoski (1988). The interrows maintained a higher potential save for small events in which greater recharge may have occurred on rows than in interrows.

Table 9. Regression constants on spatial variance and mean soil water content

$$\mathrm{VAR\ BR}\ (\theta) = 0.00215\ \theta\ - 0.00053 \quad r = 0.54$$

$$\mathrm{VAR\ TR}\ (\theta) = 0.00113\ \theta\ - 0.00026 \quad r = 0.55$$

$$\mathrm{VAR\ OR}\ (\theta) = 0.00142\ \theta\ - 0.00034 \quad r = 0.52$$

$$\mathrm{VAR\ RR}\ (\theta) = 0.000654\ \theta\ - 0.00011 \quad r = 0.52$$

Where VAR is spatial variance and θ is mean soil water content on three spatial locations.

The rate of change in spatial variance to the change in mean soil water content of the treatments is given by the slope of the regression equations. The OR slope of 0.0014 and TR slope of 0.00113 are not significantly different at 5% probability level. Lack of spatial variability in soil water content are related to losses due to evaporation (Zhai 1990) and limited depressional storage. The difference between the treatments could be due to systematic errors from non uniform plant population and from instrument insensitivity to rapid changes in soil water.

The overall variance was the lowest in RR as indicated by the lowest regression intercept. The overall general variance was highest in BR as indicated by the large regression intercept. The low spatial variance in RR may be associated with the undisturbed soil structure. The disturbance of soil structure by tillage operations and subsequent sealing of micro and meso pores by heavy storms, led to the decline in physical and hydrological properties of the soil and, ultimately, affected water distribution in the profile. The large slope value of 0.00215 indicates greater variance in BR upon drying and lower spatial variance upon wetting.

4.4.8 Analysis of temporal variance in soil water content

Van - Wesenbeech and Kachanoski (1988) found that the mean temporal variance of row position was 34% higher than the variance of the interrows in conventional tillage treatment. Zhai *et al.* (1990) obtained 13% higher temporal variance in conventional tillage rows than in interrows. In this study, the temporal variance is higher in interrows than in rows as shown in Table 10.

The mean temporal variance in water content in RR rows was almost equal to the temporal variance of interrows. In BR, mean temporal variance was 22% higher in interrows than in rows, whereas TR had a mean temporal variance of 18% higher in

Table.10 Temporal variance of profile soil water content at different sampling positions and tillage treatments

Tillage	row	2/3 interrow	interrow	average
	10^{1}			
Open ridge	45.98	62.7	71.18	59.98
Residual ridge	50.83	55.12	51.96	52.64
Basin ridge	72.83	89.09	95.54	85.82
Tie ridge	74.71	89.55	93.30	85.85

the interrows than rows. The mean temporal variance was significantly different in both rows and interrows between BR and RR, BR and OR (Table 10) but there was no significant variation between BR and TR.

The reduction in temporal variability on rows and interrows in RR was related to the minimal depression storage on the interrows and high runoff from the treatment. In OR, the temporal variance in water content was about 25% higher in the interrows than in the rows. The limited depressional storage capacity limits the recharge to the rows creating a wide temporal variance between rows and interrows.

The measured temporal dependence on spatial variability and spatial dependence on temporal variability in profile soil water content for the 4 tillage practices, created a variable crop water demand function within the field which is subjected to similar agroclimatic conditions.

4.4.9 Infiltration rate

Table 11 shows cumulative infiltration and equilibrium infiltration rates on rows and interrows measured soon after cultivation and after harvesting.

There was a drop in cumulative infiltration capacity on rows by about 12% on OR, BR and TR treatments but an increase in cumulative infiltration of about 3% on RR treatment. Equilibrium infiltration on rows dropped by over 44%, 43%, 41% in OR, BR and TR respectively and by 3% in RR (Figure 15a.i and ii).

Significant reductions in equilibrium and cumulative infiltration on interrows were observed in BR with 45% drop in equilibrium infiltration rate, 24% reduction in cumulative infiltration, followed by TR with 28% drop in equilibrium infiltration rate and 9% drop in cummulative infiltration (Figure 15b.i and ii).

The post tillage equilibrium infiltration rates were generally lower in interrows than in the rows with 61% higher in OR rows than interrows, 64% higher in BR rows than interrows, 35% higher in TR rows than interrows and were about 1% higher in RR

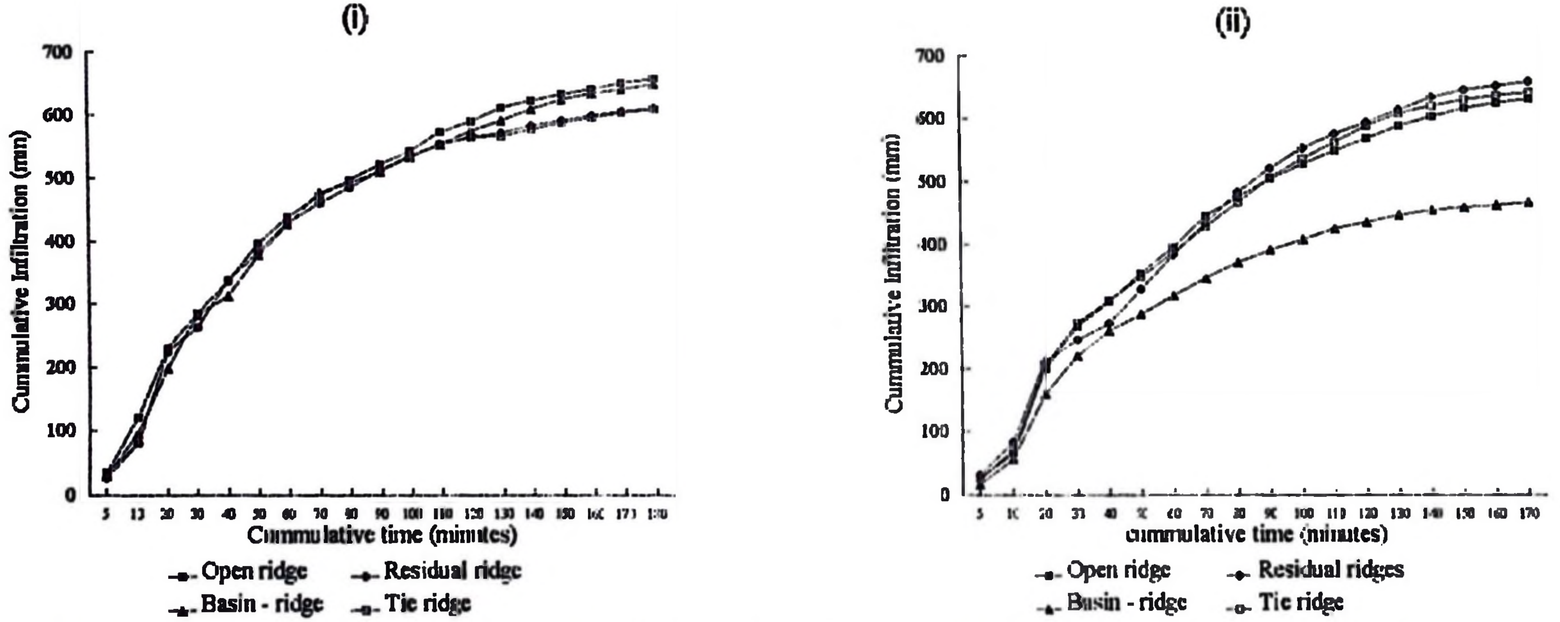


Figure 15b. Infiltration capacity measured in interrows soon after cultivation (i) and after harvesting (ii).

rows than interrows. But also, the post harvesting equilibrium infiltration rates were 32%, 66%, 21% and 1% higher on rows of OR, BR, TR and RR than interrows respectively. The significant reduction in equilibrium infiltration in BR were possibly due to increase in siltation in basins, the development of a crust surface and partly because basins created a direct interface with a clay rich (B_{t2}) horizon (Appendix 1a). The minimal change in cumulative infiltration in RR treatment was attributed to the minimal tillage practices done on the plots.

Table 11 Effect of tillage on water infiltration rate

	Equilibrium infiltration				Cumulative infiltration			
Tillage	(i)	(f)	d(i-f)	%	(i)	(f)	d(i-f)	%
	Rows cm h				mm	mm	Rows mm	
OR	13.4	7.46	-5.94	44	750	662	-88	12
PR	5.23	5.06	-0.17	3	597	615	18	-3
BR	11.02	6.31	-4.71	43	745	652	-93	12
TR	10.02	5.89	-5.13	41	735	613	-122	17
	Tillage interrow					Interrows		
OR	5.28	5.07	-0.21	4	636	600	-36	6
RR	5.18	5.11	-0.07	1	663	566	-97	15
BR	3.96	2.17	-1.79	45	471	358	-113	24
TR	6.48	4.67	-1.81	28	646	586	-60	9

(i) post tillage infiltration on rows and interrows. (f) post harvesting infiltration rate on rows and interrows. d(i - f) is the change in equilibrium and cummulative infiltration with time

In this regard, the higher soil water content in BR was partly attributed to long term infiltration process through basins, the large depression storage and reduced evaporation losses from the U-shaped basins compared to the sinusoidal ridge furrow pattern in the OR (5 m long), TR (1.5 m spacing of ties) and RR treatments.

4.5 The effect of traditional tillage practices on surface runoff

Table 12a gives total surface runoff collected from the experimental plots in 16 rainfall events as follows:

Table 12a: Total runoff and runoff coefficients

Treatment	Total Ro (mm)	Ro Rf
OR	96.66	0.29
RR	157.11	0.47
BR	33.33	0.10
TR	59.51	0.18

Ro is total surface runoff (mm)

Ro Rf is runoff coefficient

Runoff data in Table 12a show the highest surface runoff was measured in RR with 157.11 mm of water collected representing 47% of rainfall received. The lowest runoff was measured in BR treatment with 33.33 mm collected in 16 rainfall events. This

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil characterization.

The results of soil profile description and chemical analysis are reported in Appendix 1a and 1b, respectively. The soil has low residual nitrogen and organic carbon content. The sodium content decreases with depth from about 0.09 me/100g in the A_p horizon to 0.05 me/100g in B_{t5}. The soil is acidic with an average pH of 5.5 in the plough layer and CEC and exchangeable bases were higher in 0 - 25 cm depth than in subsequent horizons. Organic C, total N and available P also decreased from about 1.08%, 0.11% and 13 mg/g in 0 - 25 cm depth respectively (Appendix 1b).

Textural analysis indicates a general increase in clay with depth from 33% in the 0 - 15 cm depth to 69% at 76 - 115 cm depth. A significant proportion of sand in the 0 - 15 cm and 15 - 28 cm depth makes the aggregates friable and thus slake upon rain drop impact. Saturated hydraulic conductivity decreases with depth from 0.76 cm/h in the 0 - 15 cm depth to about 0.056 cm/h above 76 cm depth as indicated in appendix 1b.

Table 12b: Summary of analysis of variance on surface runoff

Replication	NS	NS	NS	NS	NS	NS	NS	NS
Treatments	*	*	*	*	*	*	*	*
CV (%)	18.02	4.71	17.43	17.36	12.59	16.41	29.05	2.37
Means (mm)								
OR	1.73^{b}	1.54^{b}	0.48^{a}	1.23^{a}	6.07^{b}	11.23^{b}	8.02^{b}	35.20^{b}
RR	2.77^{a}	1.71^{a}	0.47^{a}	1.23^{a}	12.50^{a}	23.13^{a}	21.40^{a}	49.10^{a}
BR	0.27^{d}	0.49^{c}	0.00^{b}	0.00^{b}	3.73^{c}	0.73^{d}	1.60^{c}	20.40^{d}
TF	1.20^{c}	0.49^{c}	0.00^{b}	0.17^{b}	3.77^{c}	7.03^{c}	10.60^{b}	26.10^{c}
S.E.	±0.077	±0.137	±0.047	±0.135	±1.611	±0.223	±0.052	±0.009
LSD	0.268	0.045	0.045	0.114	0.819	1.73	3.04	0.223
	13-11-93	6-12-93	11-12-93	12-12-94	27-12-93	21-1-94	25-1-94	24-1-94
Replication	NS	NS	NS	NS	NS	NS	NS	NS
Treatments	*	*	*	*	*	*	*	*
C.V.%	16.36	21.55	13.68	17.60	211.83	6.29	21.85	3.64
OR	6.03^{b}	3.20^{b}	2.17^{b}	1.53^{a}	2.17^{b}	13.41^{b}	1.57^{a}	1.07^{c}
RR	6.93^{a}	3.93^{a}	2.43^{a}	1.70^{a}	9.53^{a}	16.71^{a}	1.67^{a}	1.90^{a}
BR	2.77^{c}	0.53^{d}	0.03^{d}	0.00^{c}	0.00^{b}	2.3^{d}	0.00^{b}	0.48^{c}
TF	3.43^{c}	1.17^{c}	0.17^{c}	$0.13b^{b}$	0.17^{b}	4.47^{c}	0.07^{c}	0.54^{c}
S.E.	±0.226	±0.047	±0.135	±1.61	±0.223	±0.052	±0.0091	
LSD	0.783	0.475	0.164	0.135	0.773	-	0.179	0.032
	26-1-94	27-1-94	29-1-94	31-1-94	5-2-94	7-2-94	9-2-94	12-2-94

Means with different superscripts are significantly different at 5% probability level by the Duncan's New Multiple Range Test

NS = Not significant ($P > 0.05$)
* : Significant ($P < 0.05$)

mm/h. In BR rainfall intensities equal or greater than 8.6 mm/h generated surface runoff whereas 6.4 mm/h generated runoff in TR treatment.

Cases of basins being overtopped were prevalent only during double storms spaced within short durations. Basin ridge effectiveness declined with time because of gradual reduction in basin capacity due to silt accumulation from the rows and from the side banks. The siltation and sealing of pore system with fine earth reduced the intake capacity of the basins. Similarly, direct splashes on rows were spread off the field and led into the collection tanks.

Similar findings have been reported on tie ridges and open ridges under conventional cultivation systems by Hullugalle (1987) on upland alfisols in Sudan and by Jones and Stewart (1990) on basins performance in the state of Indiana.

Sources of error in runoff estimation were associated with uneffective blocking mechanisms between adjacent treatments. This resulted in spill-over from other treatments. But also, estimates were made for storms which overtopped runoff tanks.

Tie ridges can effectively be used for only low rainfall events like those prevalent in this area and subsequently removing ties and/or ridges when high rainfall events are anticipated. However, this practice can be properly planned if there is good knowledge of rainfall distribution pattern and precise prediction and forecast on rainfall return periods in which certain intensities can be equaled or exceeded.

4.6 The effect of traditional tillage practices on plant growth and grain yield.

Maize emerged about 7 days after planting in all tilled plots. However, the emergency percentage was lower in residual ridges with a stand count of 85%, two weeks after planting. During the first two weeks after emergency there was no difference in plant size among the treatments. After 30 days, growth and development differences began to show up in terms of plant size and stature.

4.6.1 Plant height

Mean plant heights as influenced by the farming practices are reported in Table 13a. At 59 DAP, basins showed more rapid growth with plant height recorded: 109.1 cm in OR, 92cm in RR, 121.1cm in BR and 110.3 cm in TR. Mean separation using Duncan's New Multiple Range Test at 5% probability level showed significant differences between treatments from 46 DAP to 75 DAP. Prior to this time, differences in plant height were not significant. The highest growth rate was observed in BR with elongation rate of 2.11 cm/day at 59 DAP (Table 13b), while the lowest growth rate was observed in RR with an elongation rate of 1.39 cm day. Treatments TR had an intermediate growth rate of 1.93 cm day whereas OR grew at 1.84 cm/day. Beyond 75 days, maize growth declined in BR, TR and OR whereas growth in RR picked up. The most active growth stage was from 46 DAP to 75 DAP as shown in table 13b. The slow growth in residual ridges was primarily due to low soil water status due to limited infiltration and greater nutrient losses through high runoff discharges.

Table 13a **Summary of analysis of variance on plant height (cm) measurements**

DAP	Emerge %	14	29	46	59	75	92
Replications	NS	NS	NS	NS	NS	NS	NS
Treatment	*	NS	*	*	*	*	*
OR	91.7	6.9^b	16.0^a	41.6^b	109.1^b	124.0^b	139.7^c
RR	85.0	7.1^b	13.7^b	37.1^c	92.0^c	113.2^c	133.2^d
BR	93.7	7.7^a	16.1^a	46.1^a	121.1^a	130.4^a	147.8^a
TR	94.0	7.1^b	16.1^a	40.7^b	110.3^b	125.4^b	142.5^b
s.e	±1.90	±0.12	±0.11	±0.76	±2.41	±0.46	±0.44
LSD	6.58	0.40	0.38	2.63	8.43	1.58	1.52
C.V (%)	3.62	5.61	2.46	6.36	7.80	1.28	1.08

Emerge. % stand for the emergency %; DAP stand for days after planting.

NS Not significant ($P > 0.05$)

* Significant ($P < 0.05$)

means with different superscripts are significantly different at 5% probability level by Duncan's New Multiple Range Test.

Table 13b **The effect of traditional tillage practice on maize growth rate (cm/day)**

DAP	14	29	46	59	75	92	106
reps	NS	NS	NS	NS	NS	NS	NS
Treat	NS	NS	*	*	*	NS	*
OR	0.49	0.55	0.95^{b}	1.84^{c}	1.65^{c}	1.56	1.42^{ab}
RR	0.48	0.47	0.80^{c}	1.39^{d}	1.52^{d}	1.53	1.33^{b}
BR	0.59	0.72	1.05^{a}	2.11^{a}	1.96^{a}	1.66	1.47^{a}
TR	0.49	0.57	0.99^{b}	1.93^{b}	1.74^{b}	1.55	1.39^{ab}
s.e	0.0109	0.012	0.0198	0.0251	0.0109	0.0109	0.0246
C.V (%) 3.71	3.60	3.61	2.40	2.46	1.23	3.04	

Emerge. % stand for the emergency %; DAP stand for days after planting.

NS Not significant (P 0.05)

* Significant (P 0.05)

means with different superscripts are significantly different at 5% probability level by Duncan's New Multiple Range Test

4.6.2 Tasselling/ silking rate.

Tasselling plants were counted every 5 days from 17-1-94 (65 DAP). The tasselling percentage per treatment is presented in Table 14a. The variations in time of germination and emergence and the intermittent dry spells within the growing season are largely responsible for phenological variations.

Table 14a Summary of analysis of variance on tasselling rate

Days	65days	70days	75days	80days
reps	NS	NS	NS	NS
treatment	*	*	*	*
OR	23^{b}	38^{b}	59^{b}	81^{b}
RR	15^{c}	33^{c}	50^{c}	76^{c}
BR	29^{a}	47^{a}	64^{a}	83^{a}
TR	27^{ab}	45^{a}	63^{ab}	83^{a}
s.e	±1.08	±1.09	±1.16	±0.365
LSD	4.28	3.96	4.02	1.26
C.V. (%)	14.43	9.23	6.80	1.56

NS Not Significant at ($p > 0.05$)

* Significant ($P < 0.05$)

means with different superscripts are significantly different at 5% probability level by The Duncan's New Multiple Range Test.

Since the leaf numbers do not show significant differences between treatments, it is anticipated that higher water use efficiency and crop evapotranspiration will be closely related to the LAI. The tasselling stage coincided with the major soil water recharge cycles. The high soil water recharge from the basin led to sustainable leaf elongation processes. Unlike number of leaves per plant, LAI responded to soil water status. Similar observations have been reported by Bennet and Hammond (1983).

Table 14b Summary on analysis of variance on number of leaves per plant

Days	10	30	35	61	76	93
reps	NS	NS	NS	NS	NS	NS
treatments	NS	NS	NS	NS	*	NS
OR	3	7	12	12	11	12
RR	3	7	12	12	9	12
BR	3	9	13	12	12	12
TR	3	8	12	11	11	11
CV (%)	-	15.1	5.37	8.43	4.31	10.73

NS Not Significant at ($p > 0.05$)

* Significant ($P < 0.05$)

means with different superscripts are significantly different at 5% probability level by The Duncan's New Multiple Range Test.

4.6.4 Dry matter yield (DMY)

The mean dry matter yield from five plant samples is shown in Table 14c. The highest dry matter yield was measured in basins and the lowest dry matter yield at tasselling stage was measured in residual ridges as follows: 5974 kg/ha in BR, 5861 kg/ha in TR, 5857 kg/ha in OR and 4545 kg/ha in RR. At both stages of growth DMY from BR was

Table 14c: Summary of analysis of variance on effect of tillage on leaf area index, dry matter yield, grain yield and shelled 1000 grain weight

	Leaf area index 65 DAP	Leaf area index 93 DAP	Dry matter yield (kg/ha) 65 DAP	Dry matter yield (kg/ha) 93 DAP	Grain yield (kg/ha)	1000 grain weight	Stand count at harvest
Replications	NS	NS	*	NS	*	NS	NS
Treatments	*	*	*	*	*	NS	*
C.V (%)	20.9	1.46	3.53	3.96	1.54	6.17	13.25
Means							
CR	5.38^a	5.03^a	5857^a	9681^a	7541^b	298.67^b	43
MP	[illegible].88^b	3.52^b	4545^b	8094^b	5064^c	291.67^b	43
BB	4.66^a	5.15^a	5974^a	9912^a	6249^a	327.00^a	45
TF	4.41^a	5.04^a	5861^a	9683^a	5822^b	319.33^a	31
S.E	± 0.525	± 0.041	± 113.2	±213.7	±50.7	±6.17	±3.1
LSD	1.82	0.14	392	740	176	19.0	

Means with superscript differ significantly at 5% probability level by the Duncan's New Multiple Range Test

NS Not significant (P > 0.05)
* Significant (P < 0.05)

CHAPTER FIVE

CONCLUSIONS AND RECOMENDATIONS

5.1 The effect of traditional tillage on physical properties of the soil

The effect of traditional tillage practices on dry bulk density and total porosity of the soil was not significant within the one season of the trial.

Tillage practices lowered the row dry bulk density of the soil in OR, BR and TR (1.28 Mg/m^3) within the 0 - 5 cm depth. Beyond this depth traditional tillage operation did not have significant impact on the dry bulk density and total porosity of the soil.

Post harvesting dry bulk density of the soil. indicated a gradual rise by about 0.08 Mg/m^3 in OR, BR and TR and about 0.02 Mg/m^3 on RR.

Post harvesting total porosity declined by about 3% within the 0 - 5 cm depth of treatments OR, TR and BR and an insignificant change in porosity of about 0.38% in RR. Interrow total porosity declined by 1% but the variation was not systematic.

Farming practices which render minimal soil disturbance like RR tend to preserve aggregate stability. Soil aggregates in RR treatment were 5% more stable than in OR, TR and BR treatments.

5.2 The effect of tillage on hydrological properties of the soil.

In this study, traditional tillage practices significantly affected the infiltration processes, profile soil water distribution and surface runoff.

The initial equilibrium infiltration rates were higher in tilled plots than the residual ridges by about 13 cm/h on OR, 11 cm/h in BR 10 cm/h in TR and 5 cm/h in RR. Equilibrium infiltration rate on rows declined with time by about 41% and 12% on rows. Significant reductions occurred in basins with 45% and 24% drop in equilibrium and cummulative infiltration rates in BR treatment respectively.

Treatments showed a fairly significant correlation between spatial variance and the mean soil water content in the profile with correlation coefficients of about 55% in BR and TR and 52% in OR and RR.

The lowest spatial and temporal variance in soil water status occurred in RR treatment with almost equal profile soil water content on rows, interrows and at 2/3 from

The variation in interrow water content was significant between treatments at tasselling stage but BR maitained the highest interrow soil water content from 13 - 142 DAP due to large depression storage capacity.

The effect of tillage operation on surface runoff was highly significant between treatments ($P < 0.05$). Basin ridge had the lowest runoff discharge about 10% of total rainfall. TR about 18%. OR about 29% and RR had about 47% surface runoff.

5.3 The effect of traditional tillage practices on maize growth and yield

Plant growth rate was significantly affected by tillage practices. The highest growth rate was observed in BR with an elongation rate of 2.11 cm/day. whereas 1.39 cm/day in RR. 1.93 cm/day in TR and 1.84 cm/day in OR at 59 DAP. Higher growth rate was associated with the higher soil water conservation in basins. Slow growth rate in RR was associated with low soil water conservation in the treatment at the most critical stages of maize growth.

Maize tasselling rate was significantly influenced by tillage practices. Tasselling rate was significantly lower in in RR at 65 DAP.

Dry matter yield was significant at tasselling and harvesting stages. The dry matter yield was 6% higher in BR than in RR. about 1% higher than TR and OR.

Leaf area index was about 38% higher in BR than RR, 6% higher than OR but did not differ significantly between BR, TR and OR. Final LAI at harvesting was 32% higher in BR than RR, 2% higher than OR and TR.

Grain yield on a net plot was significant between treatments with 10% higher yield in BR than RR and 4% higher than TR and OR.

5.4 Recommendations

In this study, Basin tillage demonstrated high potentials in controlling runoff and promoting *in situ* soil water conservation. Basins maintained high moisture content on interrows which recharged the row and attenuated the soil water difference between rows and interrows. Better crop performance in terms of grain yield, dry matter content, tasselling rate, LAI and plant height are attributed to the soil water status in the treatment.

Effective implementation of basins and tie ridge systems demands good knowledge of rainfall pattern and distribution; proper prediction of extreme rainfall events is crucial in order to avoid waterlogging and basin degeneration during high rainfall events. Therefore, more research should be directed to basin geometry, orientation and

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7.0 APPENDICES

Appendix 1a. Soil characterization and classification of Bvumbwe Research Station.

Profile No. BVI/93

Date of description: 5-11-93

Location: Bvumbwe Research Station 15 55' S 35 04'E

Altitude: 1150m above sea level

Soil Name: Fine, kaolinitic,thermic,typic hapludalf

Physiographic Position: middle slope

Surrounding Landform: undulating land.

Microtopography: Residual ridges 10cm high on average.

Slope: < 1%

Drainage : Well drained

Land Use: Fallow for 2 years

Geological formation: Precambrian baement complex

Parent Material: Charnokitic granulite (Geological Survey Report)

Soil temperature regime: Thermic

Horizons Description

Ap 0-14cm 5YR 3/4 or 2.5YR 3/4 dark red brown: clay/sand clay: moderate strong fine crumb: friable. sticky. plastic. porous. abundant fine roots. clear/abrupt boundary.

Bt1 14-25cm 2.5YR 3/4 and 2.5YR 4/4 red brown. clay. strong moderate fine subangular blocky. firm. sticky. plastic. porous.common fine roots. abrupt smooth boundary.

Bt2 25-76cm 2.5YR 3/6 red or 2.5YR 4/4. clay (smooth but not shiny. firm on the brittle part with peds actually shattering. sticky.plastic. distinct cutans. porous. common fine roots. clear smooth boundary.

Bt3 76-115cm 2.5YR 3/6 dark red clay (but not shiny). firm (brittle). sticky.plastic. clear cutans. dark films of Fe or Mn cement. porous. few weathered biotite. fine roots. diffuse boundary.

Bt_{1s} 115-145cm 2.5YR 3/6 dark red. clay but not slimmy. sticky. plastic. porous. abundant mica flakes. few roots. diffuse boundary. dark cutans.

Bt$_{45}$ 145-163cm Transitional 2.5YR 4/6 red or 2.5YR 3/6 (Smooth and slimmy).

massive. sticky. plastic. porous. mica flakes.

Bt$_5$ 163-200cm 2.5YR 3/6 red. massive. sticky. plastic. porous with mica flakes.

Appendix 1b Physico-chemical properties of profile BV1

Depth (cm)	K_s cm/h	Ph H_2O	pH $CaCl_2$	ρ_b Mg cm^{-3}	Silt %	Clay %	Class	C %	N %
0-14	0.76	5.97	4.78	1.35	10	33	SCL	0.76	0.01
14-25	0.57	5.53	4.87	1.35	9	35	SCL/SC	1.08	0.11
25-76	0.23	5.00	4.19	1.38	8	55	c	0.42	0.07
76-115	0.056	4.87	4.75	1.40	4	69	C	0.12	0.07
115-145	-	5.15	4.96	1.39	7	61	C	0.03	0.03
145-163	-	4.91	4.82	1.44	7	51	C	0.03	0.00
163-200	-	5.00	4.73	1.44	8	53	C	0.00	0.00

Appendix 1b continued.

Depth	P ug/g	Na (me/100g	K (me/100g)	Ca (me/100g)	Mg (me/100g)	Al (me/100g)	ECEC Fe_2O_3	Free Fe_2O_3
0-14	13	0.09	0.23	12.31	4.42	0.13	17.99	8.37
14-25	14	0.07	0.67	17.44	6.45	0.25	25.52	8.57
25-76	11	0.08	0.74	3.09	2.39	0.25	7.23	10.22
76-115	3	0.07	0.53	3.19	3.28	0.18	7.86	11.84
115-145	3	0.07	0.37	2.47	5.76	0.10	9.39	10.43
145-163	3	0.05	0.31	2.79	3.12	0.15	6.91	9.69
163-200	3	0.05	0.28	13.30	9.72	0.05	23.87	10.22

Appendix 1b continued trace element analysis

Depth	Cu (ppm)	Zn (ppm)	Mn (ppm)
0 - 15	2.44	12.48	4.38
50 - 67	2.34	4.68	14.52
67 - 110	1.12	206	2.52

Appendix 2a. Meteorological data summary

				Mean monthly value			
Month	Tmax °C	Tmin °C	RH (%)	Wind speed (m/s)	Sunshine (hrs)	Rainfall mm	E(pan) mm
October	27.7	16.6	66	30	8.3	3	6.6
November	25.9	16.4	75	25	6.5	42	4.0
December	27.5	18.5	71	10.2	7.5	26	5.9
January	25.2	17.8	81	19.8	7.1	88	3.8
February	24.6	17.3	75	17.9	9.0	82	4.4
March	24.3	16.9	76	18.9	7.5	46	4.3
April	24.1	15.4	77	23.0	8.6	3	-

Appendix 2b Distribution of rainfall 1993/94 season - Pentade analysis

Period	Pentade	Five day Mean Rain	RI30	RI60
1 - 5 Oct.	1	0.76	6.9996	3.3
6 - 10	2	0	0	0
11-15	3	0	0	0
16 - 20	4	1.06	1.3998	0.9588
21 - 25	5	0	0	0
26 - 30	6	0	0	0
31- 4 Nove	7	2.1	12.798	10.2
5 - 9	8	15.9	21.6	23.7
10 - 14	9	6.68	51.876	29.5
15 - 19	10	0.52	0	0
20 - 24	11	0	0	0
25 - 29	12	0.42	1.8	0.9
30 - 4 Dece	13	0.2	12.798	10.6
5 - 9	14	1.68	2.898	6.9
10 - 14	15	3.84	20.196	12.6
15 - 19	16	0.96	0.3996	1.4
20 - 24	17	1.38	8.598	6.9
25 - 29	18	7.74	28.5996	16.4
30 - 3 Jan	19	3.1	4.2	0
4 - 8	20	18.18	3.84	47.0
9 - 13	21	0	0	0
14 - 18	22	0.9	3.1998	3.83
19 - 23	23	8.3	17.5998	23.5
24 - 28	24	19.92	56.796	0.45
29 - 2 Febru:	25	4.1	11.19996	53.6
3 - 7	26	13.76	9.6	10.1
8 - 12	27	26.6	17.4	1.2
13 - 17	28	5.4	18	4.8
18 - 22	29	0	0	0
23 - 27	30	0.26	11.6	9.3
28 - 4 March	31	2.2	1.8	11
5 - 9	32	1.54	4.8	2.3
10 - 14	33	5.54	13.8	6.8
15 - 19	34	0.1	0	0
20 - 24	35	0	0	0
25 - 29	36	19.24	17.4	13.9
30 - 4 April	37	0	0	0
5 - 9	38	0	0	0
10 - 14	39	0	0	0
15 - 19	40	0	0	0
20 - 24	41	0	0	0
25 - 29	42	2.12	0	0
30 - 4 May	43	0.1	0.4	0.02

Appendix 3a. Estimated volumetric soil water content at 0 - 15 cm depth in rows, interrows and at 2/3 distance from interrows

Location row Depth 0-15cm

Days	OP	RP	BP	TP
0	0.25	0.25	0.245	[illegible]
2	0.265	0.26	0.265	0.255
4	0.245	0.25	0.25	0.255
7	0.24	0.25	0.245	0.245
9	0.235	0.25	0.245	0.245
13	0.3	0.285	0.305	0.31
16	0.3025	0.305	0.3025	0.3025
19	0.265	0.295	0.275	0.275
23	0.325	0.305	0.325	0.325
26	0.285	0.29	0.29	0.285
29	0.3125	0.305	0.325	0.325
31	0.275	0.285	0.29	0.29
33	0.3275	0.325	0.3225	0.3225
35	0.295	0.31	0.295	0.285
40	0.3275	0.3225	0.325	0.325
42	0.35	0.33	0.355	0.36
45	0.365	0.355	0.395	0.39
47	0.325	0.32	0.335	0.325
51	0.395	0.39	0.38	0.385
54	0.445	0.43	0.445	0.445
57	0.415	0.405	0.405	0.41
60	0.365	0.365	0.415	0.405
62	0.385	0.385	0.4	0.4
64	0.335	0.335	0.365	0.36
67	0.295	0.305	0.34	[illegible]
69	0.325	0.315	0.34	0.33
70	0.35	0.335	0.375	0.355
75	0.33	0.4	0.415	0.405
81	0.3325	0.3775	0.34	0.34
85	0.3325	0.33	[illegible]	[illegible]
91	0.35	0.36	[illegible]	0.365
95	0.315	0.34	0.3475	[illegible]
100	0.295	0.275	0.295	0.3
105	0.3075	0.315	0.31	0.31
109	0.3225	0.3225	0.3225	[illegible]
114	0.29	0.295	0.285	[illegible]
119	0.27	0.27	0.275	0.275
124	0.27	0.27	[illegible]	[illegible]
129	0.265	0.265	0.27	[illegible]
134	0.265	0.255	[illegible]	[illegible]

Location interrow Depth 0-15cm

Days	OP	RP	BP	TP
0	0.25	0.26	0.25	0.25
2	0.25	0.26	0.255	0.27
4	0.26	0.26	0.25	0.25
7	0.31	0.31	0.31	0.31
9	0.28	0.28	0.29	0.29
13	0.295	0.28	0.305	0.305
16	0.315	0.285	0.325	0.315
19	0.275	0.275	0.305	0.23
23	0.3275	0.325	0.3225	0.3225
26	0.305	0.29	0.3125	0.305
29	0.34	0.315	0.375	0.355
31	0.325	0.3	0.345	0.325
33	0.3275	0.325	0.3225	0.3225
35	0.295	0.295	0.305	0.305
40	0.33	0.325	0.33	0.33
42	0.33	0.375	0.44	0.43
45	0.41	0.395	0.48	0.45
47	0.435	0.4	0.501	0.47
51	0.385	0.385	0.485	0.435
54	0.4805	0.45	0.501	0.4905
57	0.4305	0.42	0.445	0.435
60	0.4075	0.405	0.4475	0.405
62	0.365	0.36	0.385	0.39
64	0.36	0.3575	0.375	0.38
67	0.375	0.36	0.43	0.41
69	0.395	0.385	0.4	0.4
70	0.4275	0.405	0.4475	0.405
75	0.38	0.3575	0.375	0.35
81	0.445	0.39	0.43	0.47
85	0.3375	0.39	0.4125	0.4
91	0.3575	0.3625	0.3475	0.3575
95	0.3725	0.3675	0.3375	0.3725
100	0.335	0.335	0.34	0.3375
105	0.315	0.315	0.315	0.315
109	0.3275	0.3275	0.3375	0.3325
114	0.32	0.3275	0.325	0.325
119	0.325	0.3275	0.34	0.335
124	0.3175	0.3175	0.325	0.3225
129	0.295	0.295	0.3	0.305
134	[illegible]	0.285	[illegible]	0.27
142	[illegible]	0.255	[illegible]	[illegible]

Location 2/3 distance from interrow Depth 0-15cm

Days	OP	RP	BP	TP
0	0.25	0.25	0.24	0.24
2	0.25	0.24	0.25	0.235
4	0.255	0.265	0.26	0.26
7	0.265	0.275	0.27	0.27
9	0.295	0.28	0.3	0.3
13	0.305	0.295	0.325	0.315
16	0.305	0.3	0.3	0.31
19	0.26	0.28	0.27	0.265
23	0.315	0.3	0.325	0.325
26	0.295	0.28	0.295	0.3
29	0.32	0.3	0.325	0.325
31	0.27	0.285	0.275	0.275
33	0.305	0.295	0.305	0.305
35	0.295	0.27	0.28	0.295
40	0.32	0.31	0.33	0.32
42	0.34	0.33	0.37	0.37
45	0.37	0.37	0.425	0.425
47	0.39	0.39	0.43	0.435
51	0.39	0.385	0.415	0.425
54	0.41	0.405	0.445	0.43
57	0.37	0.38	0.375	0.375
60	0.325	0.315	0.33	0.33
62	0.415	0.4	0.425	0.415
64	0.37	0.38	0.365	0.375
6	0.365	[illegible]	0.375	0.365
69	0.375	0.38	0.39	0.39
70	0.39	0.39	0.39	0.395
75	0.41	0.4	0.415	0.415
81	0.33	0.33	0.33	0.33
85	[illegible]	0.315	0.315	0.315
91	0.34	0.34	0.35	0.355
95	0.31	0.315	0.315	0.315
100	0.31	0.31	0.31	0.31
105	0.32	0.32	0.325	0.325
109	0.305	0.3	0.305	0.305
114	0.27	0.265	0.28	0.275
119	[illegible]	0.25	0.27	0.275
124	0.275	0.255	0.28	0.25
129	[illegible]	0.255	0.265	0.265
134	[illegible]	[illegible]	0.265	0.25
142				

Appendix 3b. Estimated volumetric soil water content content on rows, interrows and 2/3 distance from interrows at 15 - 28 cm depth.

Location interrow Depth 15-25cm

Days	OR	RR	BR	TR
0	0.25	0.255	0.245	0.25
2	0.25	0.26	0.26	0.26
4	0.255	0.26	0.255	0.25
7	0.25	0.25	0.25	0.25
9	0.25	0.255	0.255	0.25
13	0.26	0.265	0.27	0.265
16	0.255	0.255	0.255	0.255
19	0.255	0.265	0.25	0.255
23	0.25	0.26	0.26	0.26
26	0.25	0.26	0.25	0.25
29	0.25	0.255	0.25	0.26
31	0.255	0.255	0.255	0.255
33	0.26	0.27	0.27	0.27
36	0.26	0.26	0.28	0.265
40	0.29	0.28	0.295	0.29
42	0.29	0.29	0.305	0.295
45	0.3	0.295	0.315	0.295
47	0.3	0.295	0.305	0.305
51	0.31	0.31	0.315	0.315
54	0.31	0.31	0.33	0.33
57	0.31	0.305	0.325	0.32
60	0.295	0.285	0.31	0.295
62	0.315	0.315	0.335	0.33
64	0.3	0.295	0.32	0.295
67	0.33	0.305	0.33	0.33
69	0.325	0.31	0.325	0.325
75	0.295	0.285	0.31	0.295
81	0.295	0.29	0.29	0.3
85	0.33	0.27	0.305	0.275
91	0.3	0.29	0.27	0.295
95	0.27	0.28	0.305	0.285
100	0.285	0.265	0.285	0.265
105	0.28	0.26	0.265	0.255
109	0.265	0.255	0.255	0.265
114	0.26	0.255	0.26	0.255
119	0.255	0.27	0.28	0.265
124	0.27	0.265	0.255	0.255
129	0.255	0.255	0.265	0.265
134	0.265	0.265	0.265	0.265
142	0.26	0.26	0.26	0.275
147	0.27	0.265	0.276	0.27

Location row Depth 15-28cm

Days	OR	RR	BR	TR
0	0.24	0.255	0.245	0.245
2	0.25	0.25	0.25	0.25
4	0.255	0.26	0.255	0.25
7	0.25	0.25	0.25	0.25
9	0.24	0.265	0.26	0.26
13	0.25	0.265	0.275	0.26
16	0.26	0.255	0.255	0.255
19	0.24	0.2625	0.26	0.255
23	0.265	0.265	0.26	0.26
26	0.26	0.26	0.25	0.255
29	0.25	0.265	0.25	0.25
31	0.24	0.255	0.255	0.25
33	0.245	0.26	0.26	0.265
36	0.26	0.25	0.26	0.26
40	0.285	0.28	0.29	0.29
42	0.28	0.28	0.29	0.29
45	0.285	0.29	0.28	0.29
47	0.275	0.275	0.29	0.285
51	0.295	0.29	0.31	0.31
54	0.31	0.295	0.3	0.315
57	0.29	0.295	0.31	0.325
60	0.285	0.275	0.295	0.28
62	0.315	0.28	0.325	0.325
64	0.31	0.275	0.33	0.275
67	0.3	0.295	0.305	0.305
69	0.335	0.31	0.325	0.325
75	0.295	0.285	0.305	0.295
81	0.295	0.29	0.3	0.3
85	0.27	0.265	0.27	0.27
91	0.295	0.29	0.27	0.29
95	0.265	0.275	0.285	0.285
100	0.265	0.255	0.255	0.265
105	0.25	0.26	0.255	0.255
109	0.255	0.255	0.26	0.255
114	0.275	0.27	0.265	0.255
119	0.255	0.255	0.255	0.255
124	0.26	0.265	0.255	0.25
129	0.265	0.25	0.255	0.255
134	0.245	0.265	0.25	0.25
142	0.25	0.265	0.27	0.265
147	0.255	0.255	0.255	0.255

Location 2/3 from interrow Depth 15-28cm

Days	OR	RR	BR	TR
0	0.25	0.255	0.245	0.25
2	0.26	0.26	0.26	0.26
4	0.255	0.26	0.255	0.25
7	0.25	0.25	0.25	0.25
9	0.25	0.255	0.255	0.25
13	0.26	0.265	0.27	0.265
16	0.255	0.255	0.255	0.255
19	0.255	0.265	0.28	0.255
23	0.26	0.26	0.26	0.25
26	0.25	0.26	0.25	0.25
29	0.25	0.265	0.26	0.25
31	0.255	0.255	0.255	0.255
33	0.27	0.27	0.27	0.27
36	0.26	0.26	0.28	0.265
40	0.29	0.29	0.295	0.29
42	0.29	0.29	0.305	0.295
45	0.3	0.295	0.315	0.295
47	0.3	0.295	0.305	0.305
51	0.31	0.31	0.315	0.315
54	0.31	0.31	0.33	0.33
57	0.3	0.305	0.325	0.32
60	0.295	0.285	0.31	0.295
62	0.31	0.315	0.335	0.33
64	0.3	0.295	0.32	0.295
67	0.33	0.305	0.33	0.33
69	0.325	0.31	0.325	0.325
75	0.295	0.285	0.31	0.295
81	0.27	0.27	0.275	0.27
85	0.3	0.3	0.305	0.29
91	0.28	0.26	0.26	0.255
95	0.265	0.255	0.265	0.265
100	0.28	0.255	0.28	0.26
105	0.255	0.255	0.255	0.255
109	0.275	0.27	0.27	0.27
114	0.255	0.255	0.26	0.255
119	0.26	0.26	0.295	0.265
124	0.255	0.25	0.255	0.25
129	0.255	0.255	0.27	0.255
134	0.255	0.255	0.255	0.255
142	0.255	0.255	0.255	0.255
147	0.255	0.265	0.27	0.27

Appendix 4a Total porosity (S_t) and macroporosity (Macro) on rows

Depth (cm)	0-5		15-20		30-35		40-45	
	S_t	Macro	S_t	Macro	S_t	Macro	S_t	Macro
post tillage readings								
%								
OR	52	24	48	20	46	17	46	17
RR	49	21	48	20	45	17	46	18
BR	52	24	48	20	47	18	47	18
RR	51	24	48	20	48	18	46	18
post harvest readings								
OR	48	21	49	21	47	18	45	16
RR	48	21	47	19	46	18	45	16
BR	48	21	48	20	48	19	45	16
TR	49	22	48	20	46	18	46	17

Appendix 4b Total porosity (S_t) and macroporosity (Macro) on interrows (post tillage readings)

Depth (cm)	0-5		15-20		30-35		40-45	
	S_t	Macro	S_t	Macro	S_t	Macro	S_t	Macro
%								
OR	48	20	48	20	48	19	47	19
RR	47	19	48	20	48	19	46	18
BR	47	19	47	19	46	17	45	16
TR	47	19	47	19	46	18	46	17
post harvest readings								
OR	47	19	46	18	46	17	47	18
RR	47	19	46	19	47	18	46	17
BR	46	18	46	18	46	17	45	16
TR	46	19	47	19	46	17	46	17

S_t is calculated total porosity (%). Macro stand for calculated (%) macroporosity

Appendix 4e Dispersive index measurement

%

Depth(cm)	0 - 5	15 - 20	30 - 35	40 - 45
OR	12	12	11	11
R R	11	11	10	9
BR	12	12	12	11
TR	12	12	11	11

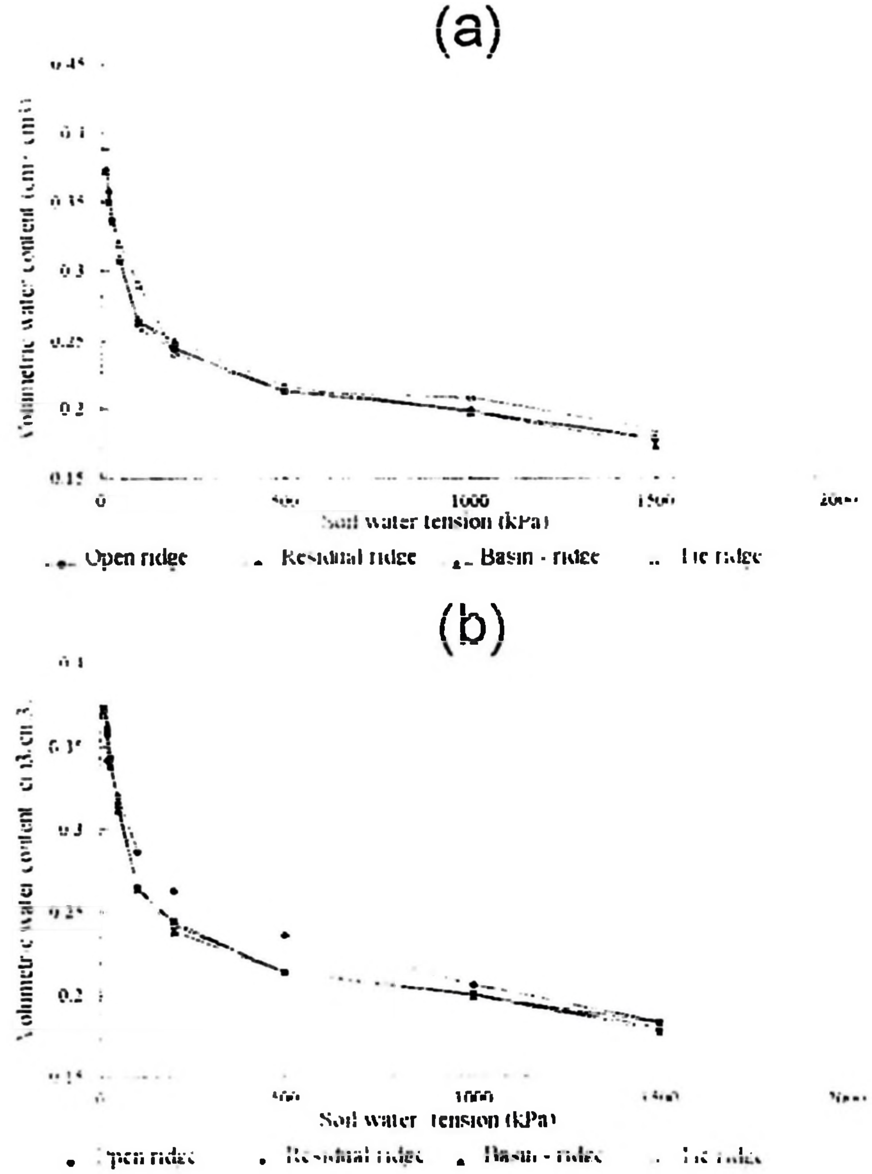
Values are cummulative scores.

DI Score range 0 - 16.

Sample number per treatment 5

Total samples 60

Appendix 5. Effect of tillage practices on soil water retention capacity at 0 - 5 cm (a) and 20 -25 cm (b) dept rows



Appendix 6 Spatial variance in soil water content

DAP	OR	RR	BR	TR
0	8.6E-06	0.000035	0.000026	0.000011
2	8.0E-06	1.0E-06	9.6E-06	0.000016
4	1.6E-06	1.6E-06	2.6E-06	8.6E-06
7	0.000091	0.000075	0.000082	0.000082
9	0.000033	0.00002	0.000017	0.000095
13	6.3E-06	0.000182	0.000011	0.000096
16	0.000016	0.000029	6.0E-06	8.3E-06
19	0.000034	0.000083	0.000033	4.0E-06
23	2.6E-06	5.7E-06	1.6E-06	0.000092
26	4.6E-06	1.7E-06	0.000012	8.6E-06
29	0.000038	0.000011	0.000011	0.000035
31	0.000062	8.3E-06	0.00011	0.000051
33	0.000014	0.000052	0.000028	0.000067
36	0.00002	0.000047	0.000028	5.6E-06
40	0.000042	4.6E-06	0.000025	0.000041
42	0.000104	0.000094	0.000208	0.000096
45	0.00002	0.000054	0.000254	0.000048
47	0.000216	0.000167	0.000536	0.000177
51	0.000011	0.000063	0.000294	0.000051
54	0.000097	0.000024	0.000022	0.000133
57	0.00008	0.000021	0.000053	0.000057
60	0.000133	0.000156	0.000183	0.000016
62	0.000018	0.00003	0.000051	0.000222
64	0.000086	0.000074	3.3E-07	0.000195
67	0.000216	0.000211	0.00029	0.000241
69	0.000124	0.000098	0.000068	0.000131
75	0.000043	0.000113	0.000048	0.000043
81	0.000295	0.000111	0.00033	0.00004
85	0.000013	0.000086	0.000114	0.000018
91	0.000096	0.000098	0.00027	0.000135
95	0.000089	0.00011	0.000217	0.000092
100	0.00002	0.000403	0.000038	0.00002
105	0.000014	6.3E-06	3.3E-07	4.6E-06
109	8.6E-06	4.3E-06	3.0E-06	3.0E-06
114	0.000048	0.000126	0.000028	0.000051
119	0.000047	0.000047	0.000034	0.000078
124	0.00004	1.6E-06	0.000038	0.000064
129	0.000011	0.000044	0.000033	0.00002
134	4.6E-06	2.0E-06	0.00008	0.000011

Appendix 7a Analysis of variance on row soil water content (planting day)

Crop stage Planting

Dept	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	NS	NS
OR	0.164	0.171	0.171	0.173
RR	0.172	0.174	0.172	0.175
BR	0.165	0.171	0.170	0.174
TR	0.168	0.171	0.169	0.171
C.V (%)	3.68	2.06	0.98	1.45

NS Not significant (P > 0.005). * significantly (P < 0.05)

Appendix 7b Analysis of variance on row soil water content (13 days after planting)

Crop stage Emergency to 3leaves

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	*	*	NS	NS
Treatments	NS	NS	NS	NS
OR	0.191	0.189	0.190	0.184
RR	0.190	0.191	0.186	0.182
BR	0.193	0.193	0.188	0.185
TR	0.193	0.193	0.187	0.183
C.V (%)	0.82	0.60	1.84	1.20

Appendix 7c Analysis of variance on row soil water content (56 days after planting)

Crop stage: Tasselling

Depth	5cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	*	*	NS	*
OR	0.336	0.357	0.364	0.369
RR	0.326	0.338	0.352	0.347
BR	0.337	0.360	0.363	0.373
TR	0.336	0.361	0.363	0.377
C.V(%)	1.14	1.73	1.77	2.78

Appendix 7d Analysis of variance on row soil water content (63 days after planting)

Crop stage Tasselling silking

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	NS	*
OR	0.258	0.295	0.295	0.340
RR	0.254	0.291	0.300	0.327
BR	0.256	0.292	0.298	0.353
TR	0.254	0.294	0.305	0.338
C.V (%)	1.9	2.08	1.50	0.93

Appendix 7e Analysis of variance on row soil water content (81 days after planting)

Crop stage Ear developement and grain filling

Depth	5 cm	15 cm	30 cm	45 cm
Reps	NS	NS	NS	NS
Treatments	*	*	*	NS
OR	0.283	0.274	0.281	0.282
RR	0.265	0.268	0.273	0.282
BR	0.288	0.283	0.286	0.284
TR	0.286	0.283	0.283	0.283
C.V. (%)	2.95	1.32	1.09	0.67

Appendix 7f. Analysis of variance on row soil water content (86 days after planting)

Crop stage Ear developement and grain filling

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	*	*	*	NS
C.V (%)	0.62	0.65	0.76	0.80
OR	0.301	0.300	0.305	0.309
RR	0.290	0.292	0.303	0.306
BR	0.302	0.303	0.309	0.313
TR	0.302	0.303	0.309	0.311

Appendix 7g. Analysis of variance on row soil water content (96 days after planting)

Crop stage	Maturity			
Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	NS	NS
OR	0.176	0.178	0.189	0.194
RR	0.182	0.183	0.191	0.198
BR	0.180	0.185	0.190	0.199
TR	0.180	0.181	0.193	0.195
C.V. (%)	2.52	2.14	1.91	3.54

Appendix 7h. Analysis of variance on row soil water content (110 days after planting)

Crop stage	Maturity			
Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	*	NS	NS	NS
OR	0.183	0.192	0.201	0.213
RR	0.183	0.189	0.207	0.208
BR	0.184	0.196	0.204	0.217
TR	0.183	0.193	0.202	0.215
C.V (%)	1.01	1.48	3.00	1.90

Appendix 7i. Analysis of variance on row soil water content (119 days after planting)

Crop stage Near harvesting time

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	*	NS	NS	NS
Treatments	NS	NS	NS	*
OR	0.180	0.187	0.186	0.202
RR	0.180	0.184	0.191	0.199
BR	0.182	0.191	0.195	0.208
TR	0.184	0.183	0.194	0.206
c.v. (%)	1.53	2.43	2.16	1.43

Appendix 8a. Analysis of variance on interrow soil water content during planting

Crop stage planting

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	*
Treatments	*	*	NS	NS
OR	0.175	0.177	0.170	0.179
RR	0.181	0.184	0.177	0.180
BR	0.176	0.175	0.169	0.178
TR	0.176	0.176	0.171	0.178
C.V (%)	0.88	1.39	2.22	2.49

Appendix 8b. Analysis of variance on interrow soil water content (13 days after planting).

Crop stage Emergency to 3 leaves

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	*	NS	NS	NS
Treatments	NS	NS	NS	*
OR	0.178	0.179	0.180	0.184
RR	0.180	0.183	0.182	0.184
BR	0.179	0.181	0.182	0.179
TR	0.177	0.181	0.179	0.180
C.V. (%)	0.81	0.90	1.03	2.15

Appendix 8c. Analysis of variance on interrow soil water content (56 days after planting).

Crop stage Tasselling

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	*	*	NS	*
OR	0.336	0.357	0.364	0.369
RR	0.326	0.338	0.352	0.347
BR	0.337	0.360	0.363	0.373
TR	0.336	0.361	0.363	0.377
C.V. (%)	1.14	1.73	1.77	2.78

Appendix 8d. Analysis of variance on interrow soil water content (63 days after planting).

Crop stage Tasselling

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	NS	*
OR	0.258	0.295	0.296	0.340
RR	0.254	0.291	0.300	0.327
BR	0.256	0.292	0.298	0.353
TR	0.254	0.294	0.305	0.338
C.V. (%)	1.90	2.08	1.50	0.93

Appendix 8e. Analysis of variance on interrow soil water content (81 days after planting).

Crop stage Silking and ear development

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	NS	NS
OR	0.309	0.322	0.335	0.337
RR	0.303	0.312	0.336	0.336
BR	0.314	0.320	0.348	0.338
TR	0.315	0.321	0.340	0.336
C.V (%)	2.71	1.48	2.32	1.02

Appendix 8f. Summary of analysis of variance on interrow soil water content (86 days after planting).

Crop stage Ear development and grain filling

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	*	*
OR	0.301	0.332	0.310	0.338
RR	0.303	0.330	0.324	0.357
BR	0.306	0.336	0.308	0.371
TR	0.301	0.327	0.312	0.345
C.V (%)	1.18	2.01	0.25	2.11

Appendix 8g. Analysis of variance on interrow soil water content (96 days after planting).

Crop stage Maturity

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	*	NS	*
OR	0.194	0.257	0.215	0.284
RR	0.195	0.264	0.231	0.275
BR	0.195	0.267	0.245	0.310
TR	0.195	0.271	0.229	0.283
C.V.(%)	1.30	1.67	7.60	1.64

Appendix 8h. Analysis of variance on interrow soil water content (110 days after planting).

Crop stage Maturity

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	NS	NS	*	*
OR	0.183	0.233	0.202	0.257
RR	0.192	0.243	0.229	0.273
BR	0.185	0.248	0.202	0.273
TR	0.190	0.241	0.208	0.256
C.V. (%)	2.65	4.57	3.79	2.69

Appendix 8i. Analysis of variance on interrow soil water content (119 days after planting).

Crop stage Near harvesting

Depth	5 cm	15 cm	30 cm	45 cm
Reps.	NS	NS	NS	NS
Treatments	*	*	*	NS
OR	0.180	0.193	0.214	0.213
RR	0.181	0.194	0.214	0.215
BR	0.181	0.193	0.218	0.222
TR	0.182	0.192	0.210	0.216
CV (%)	1.41	1.21	1.09	2.75